The Journal of Bone and Joint Surgery

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The American Orthopaedic Association
The British Orthopaedic Association
The American Academy of Orthopaedic Surgeons
The Australian Orthopaedic Association
The Canadian Orthopaedic Association
American Society for Surgery of the Hand
New Zealand Orthopaedic Association
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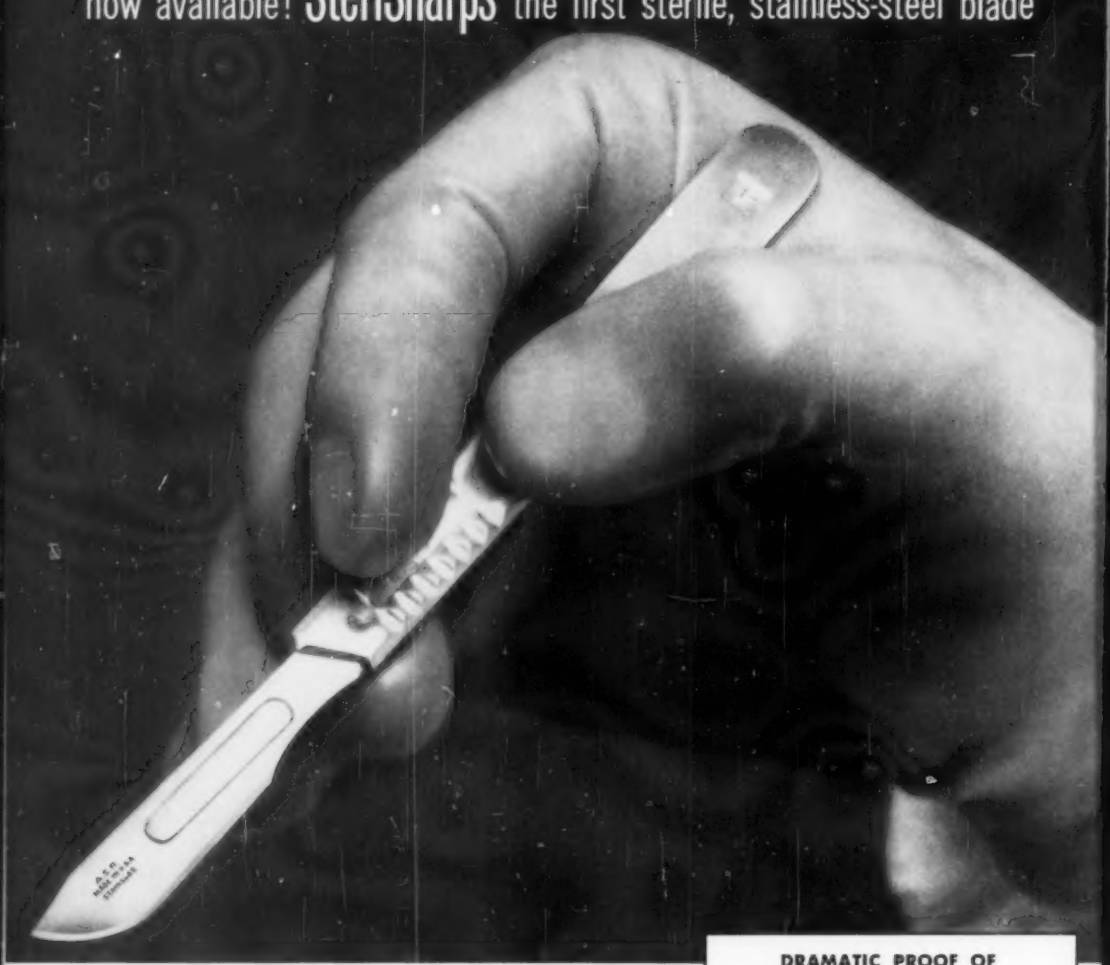

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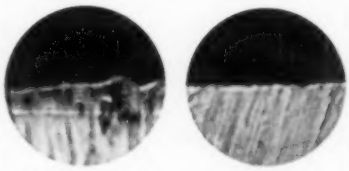

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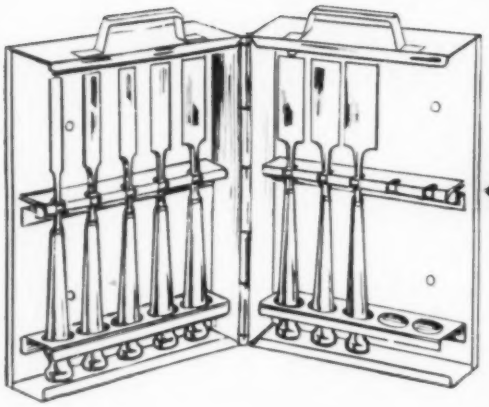

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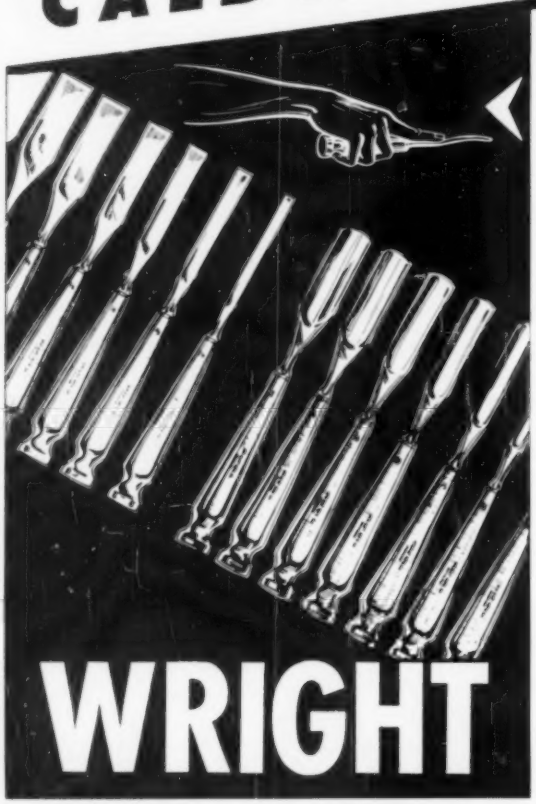

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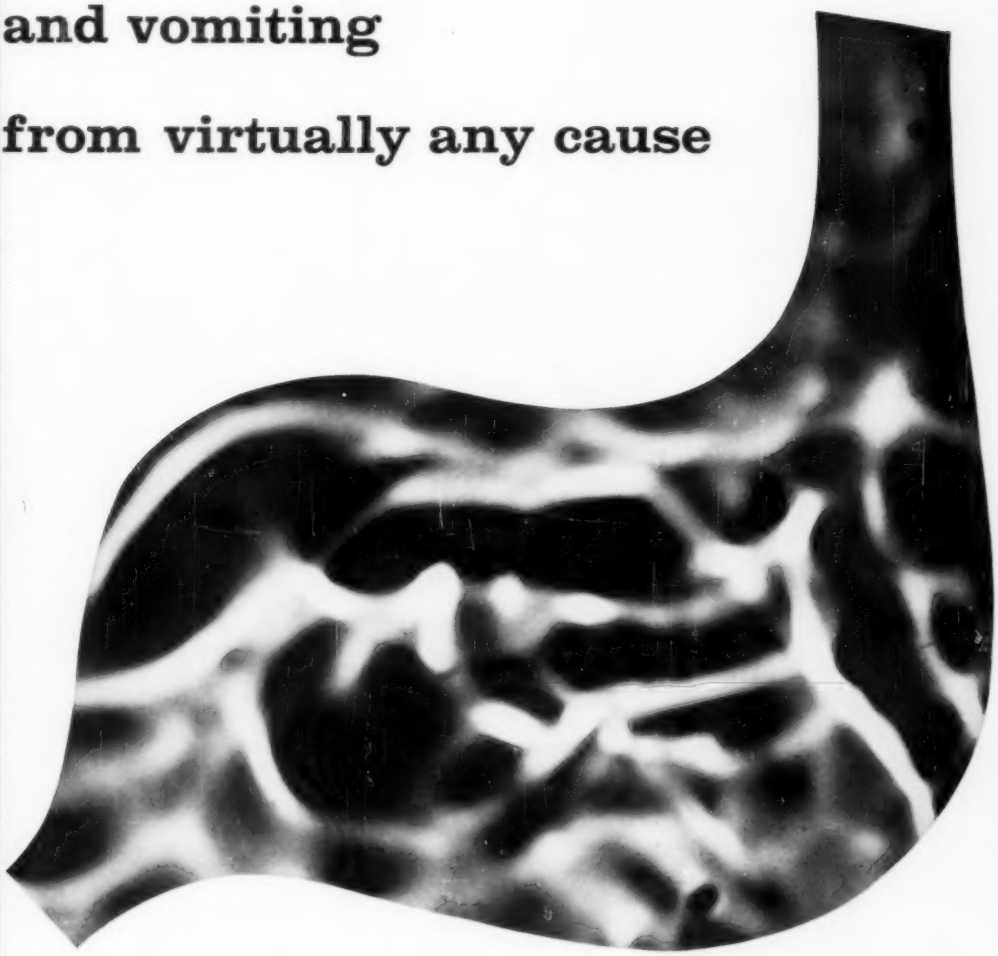

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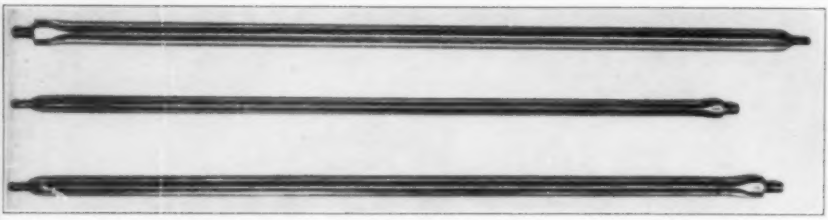

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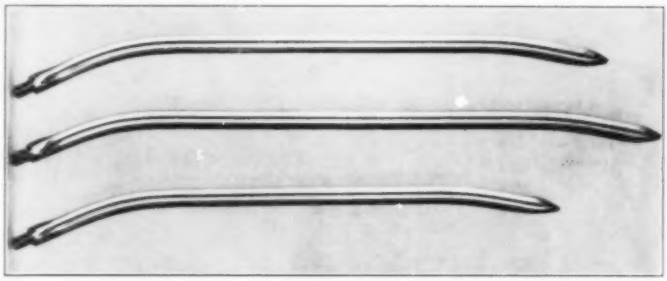

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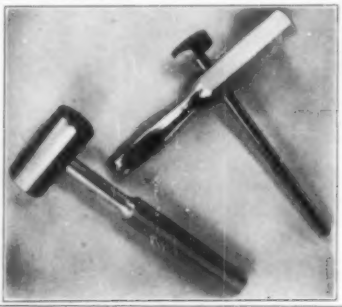

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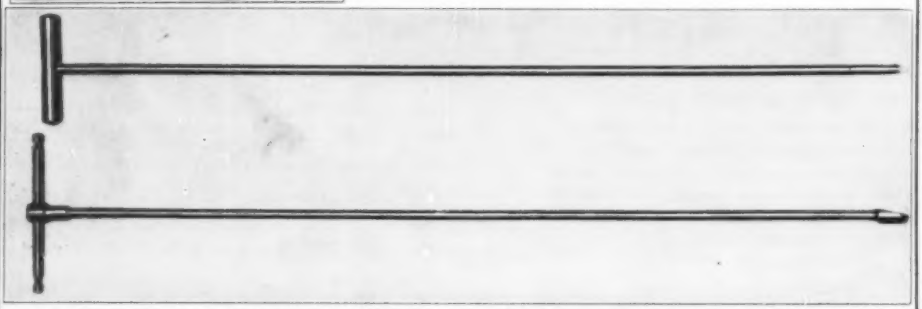

CHAS. A. SCHMIDT SURGICAL INSTRUMENT COMPANY
3689 Olive Street, Saint Louis 8, Missouri

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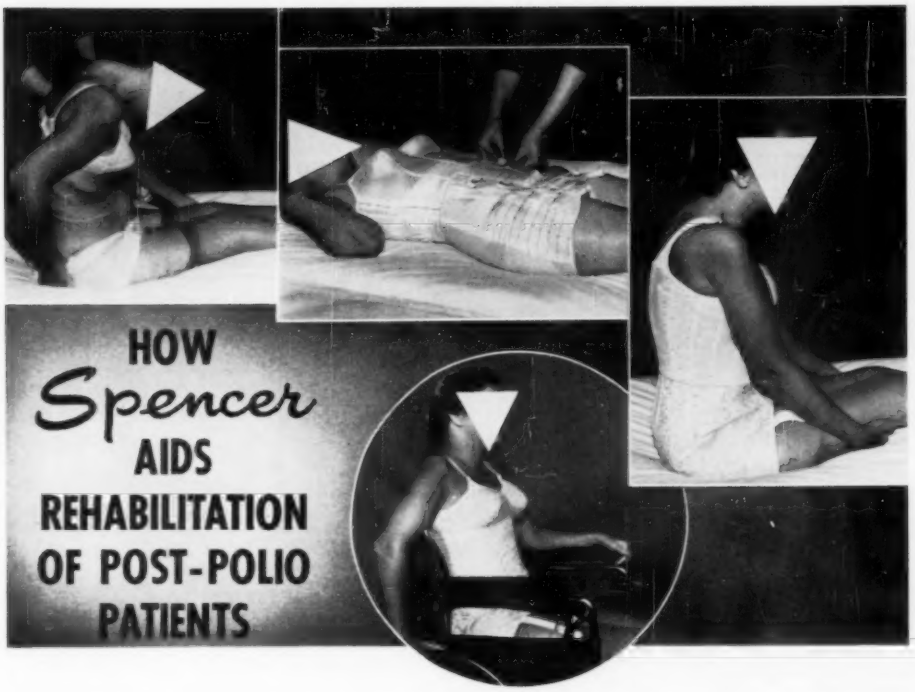

HOW Spencer AIDS REHABILITATION OF POST-POLIO PATIENTS

Eighty per cent paralyzed by polio, this young mother breathes diaphragmatically with only 50 per cent diaphragmatic function. Breathing was difficult in her old brace, causing physical exhaustion after a few hours in her wheel chair.

Her Spencer Support and Brassiere are individually designed for her to:

- Stabilize paralyzed muscles so as not to impede the action of associated active muscles.
- Elevate abdominal organs to assist pulmonary ventilation.
- Maintain skeletal alignment to prevent further deterioration.

Spencer has contributed to increasing vital capacity sufficiently to allow her to care for her home and family throughout a busy fourteen-hour day.

Mail coupon for booklet on Spencer Supports. See "Spencer Corsetiere," "Spencer Support Shop" or yellow pages of telephone directory for dealer in Spencer Supports.

SPENCER®

individually designed supports for men, women and children

SPENCER, INCORPORATED
19 Ellsworth Ave., New Haven 7, Connecticut
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Send free booklet "Spencer Supports in Modern Therapy."

Name _____ M.D.

Address _____

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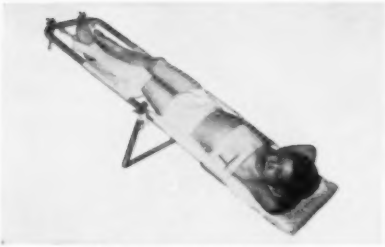
1-58

THE PORTABLE *Stryker* CHILD'S TRACTION FRAME

for Safe Traction in Children with Fractured Femurs



FOR EXTENSION TRACTION

FOR SUSPENSION TRACTION

Actual hospital tests in fractured femur cases of children have shown that the use of the Portable Stryker Child's Traction Frame greatly reduces nursing care. The attending physician can prescribe home convalescence after the first week of the usual six weeks of traction. The frame is ideally suited for children from infancy to ten years of age, easily converts from extension to suspension traction, avoids danger of circulatory complications. Completely portable, sets on any bed, disassembles for storage. Clip coupon for complete information or ordering.

PRICE No. 725 – $58.00

☐ Send me _____ frames. Bill the address below.
☐ Please send me complete details on the Stryker Dual Purpose Child's Traction Frame.

Name: _____

Hospital: _____

Address: _____

City: _____ State: _____

Stryker SURGICAL AND HOSPITAL EQUIPMENT

Orthopedic Frame Company

420 ALCOTT STREET • KALAMAZOO, MICHIGAN

Distributed in Canada by: Fisher & Burpe, Ltd., Winnipeg Exclusive Agent for Export: Schuelor & Co., 75 Cliff St., N. Y.

FOR GREATER STRENGTH AND SAFETY—

DEMAND GENUINE **NEUFELD NAILS** *and* **SCREWS**

—IN **NEUTRILIUM®**

NEUTRILIUM® is the most non-corrosive metal known to science. Its proven super-strength lends an assurance of permanence to internal fixation of the trochanteric area. This neutral, non-magnetic, homogenetic alloy is entirely inert and therefore compatible with human bone or tissue, remaining unaffected by body chemistry.

NEUFELD BONE SCREWS — of ***NEUTRILIUM®*** — are cold forged and, unlike other metals, appear to be unbreakable under maximum human pressures. Heads will not twist off during application or in actual use.

GENUINE NEUFELD NAILS and SCREWS — of ***NEUTRILIUM®*** — made only by MEDICAL RESEARCH SPECIALTIES, Loma Linda, California, are sold nationally by leading surgical and orthopaedic supply dealers.

NEUTRILIUM® *is a registered Trade Name of Medical Research Specialties.*

NEUFELD FEMORAL NAIL PLATE
Used for internal fixation of intertrochanteric and subtrochanteric fractures.
Write for descriptive literature.
MEDICAL RESEARCH SPECIALTIES
Loma Linda, California

Prescribe with confidence . . .

recommend Edwards *Pedic Shoes*

Fifty-seven years of craftsmanship go into the making of Edwards Pedic shoes, the only complete line of children's prescription shoes in America. Ideal for lateral or medial wedging, Edwards Pedics are made on tested lasts, from clinic-approved patterns. Write for the name of your nearest Edwards dealer, who is trained in prescription fitting, and for a Pedic brochure.

Pronation

COREC TRED
for mild cases
(also available in boot)

SUPER-PEDIC
for extreme cases
(also available in oxford)

Supination

PIGEON-TOE
for mild cases
(also available in oxford)

PRONA-PEDIC
for extreme cases
(also available in oxford)

Pre-Walkers

REVERSE LAST

STRAIGHT-LAST

Straight-Lasts

SURGICAL BOOT

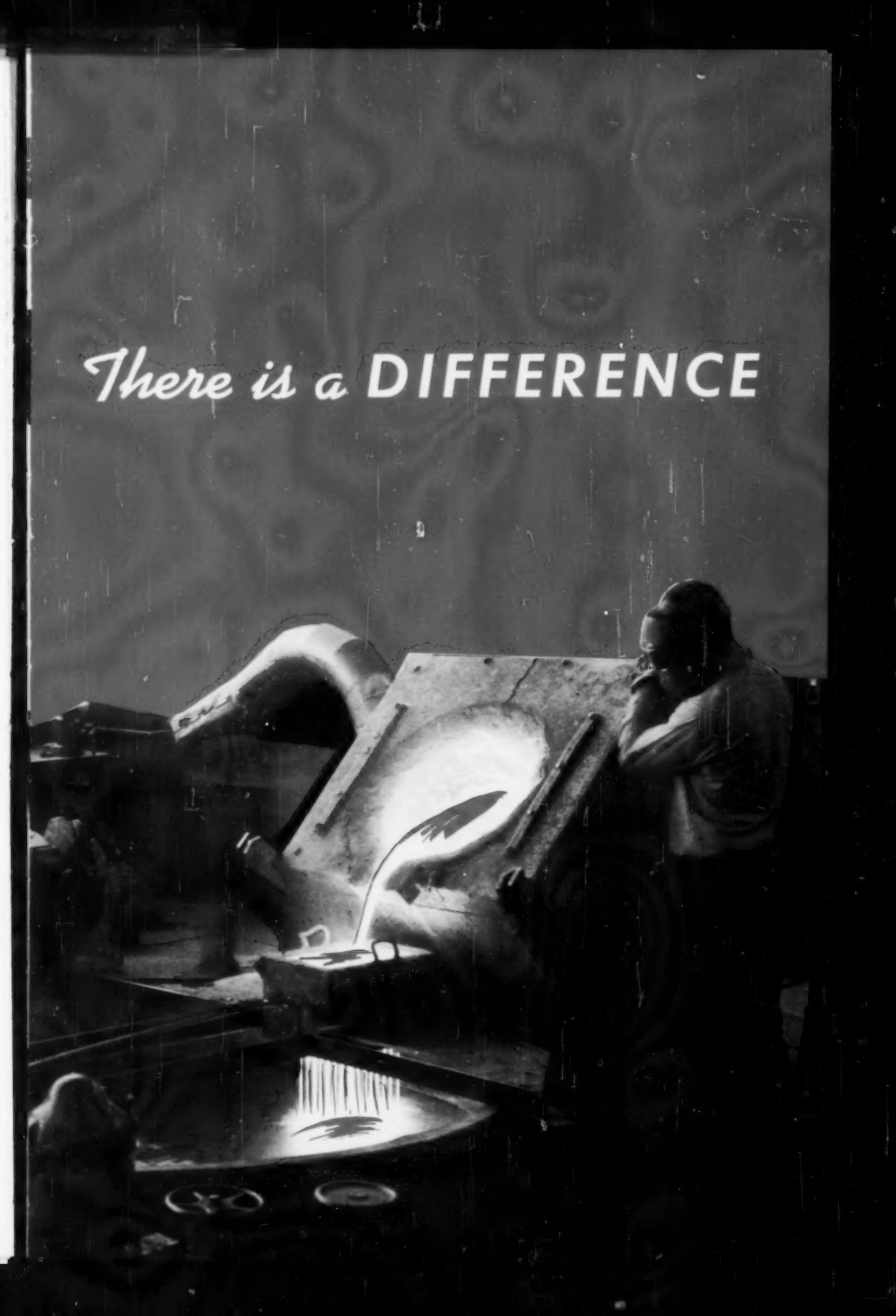
REGULAR BOOT

THOMAS HEEL
EXTENDED
COUNTER
(Also available in oxford)

Edwards®

The Shoe for Children

PHILADELPHIA 7, PENNSYLVANIA


There is a DIFFERENCE

VITALLIUM ALLOY—THE ONLY ALLOY CREATED SPECIFICALLY

The full significance of this difference has become increasingly noteworthy each year since 1936 when Vitallium was introduced to surgery. As more and more Vitallium Surgical appliances are implanted their success has been continuously reported in the literature. This record stands as a testimonial to their unqualified acceptance and versatility in surgical applications.

The difference is the Vitallium alloy. It is not a commercial alloy. Vitallium is a cobalt-chromium-molybdenum alloy developed by Austenal exclusively for surgical use. Unlike commercial alloys produced in large tonnage lots, Vitallium is prepared in relatively small quantities. It is compounded by metallurgists in Austenal's own laboratories to meet strict specifications. Maximum quality control is effected in all stages from selection of the virgin metals through formulation and production. The composition of Vitallium is kept within limits which are approximately twenty times narrower than the limits specified for commercially produced alloys.

The result is Vitallium, a uniform alloy from batch to batch made to one high standard. Furthermore, Vitallium Surgical appliances are fabricated only by Austenal—the only company in the orthopedic field with complete control of its products from alloy making to finished appliances. When you employ Vitallium Surgical appliances you are utilizing an alloy that is truly unique. There is only one quality—unquestionably the best—to merit your confidence.

FOR SURGICAL USE

FORMULATION—

More than 22 years of research and development have resulted in controlled formulation and provided greater uniformity of results.

ALLOY MAKING—

Austenal manufactures its own alloy in its own facilities from the purest metals obtainable to insure consistent quality and composition.

TESTING—

Chemical and physical property tests are made of each batch. Only after having passed these quality control tests is a batch approved as suitable for surgical use.

AND THERE ARE OTHER DIFFERENCES, TOO!

- Vitallium alloy contains no iron or steel in its formulation—it cannot rust.
- Vitallium is non-corrosive in either polished or satin finish, in contrast to other alloys used in surgery that depend upon a highly polished surface for their corrosion resistance.
- Only those Vitallium appliances designed to replace an articulating surface are highly polished for smoother function.
- The familiar satin finish on Vitallium appliances reduces glare from operating room lights.
- Vitallium appliances have proved to be compatible with, and completely inert in, human tissue.
- In 22 years of use, over 7 million Vitallium appliances have been surgically implanted.
- There has never been one authenticated case of corrosion reported where a Vitallium appliance has been used.
- Vitallium appliances may be used together in the same patient without electrolytic reaction or ill effect.
- Vitallium appliances are X-rayed for internal soundness and surface inspected by the Zyglo† penetrant method.
- Vitallium Surgical appliances merit the confidence of surgeons.

†Tr. Mk. of Magnaflux Corp.

AUSTENAL, INC. *Surgical* DIVISION
224 EAST 99TH STREET • NEW YORK 16, N. Y.

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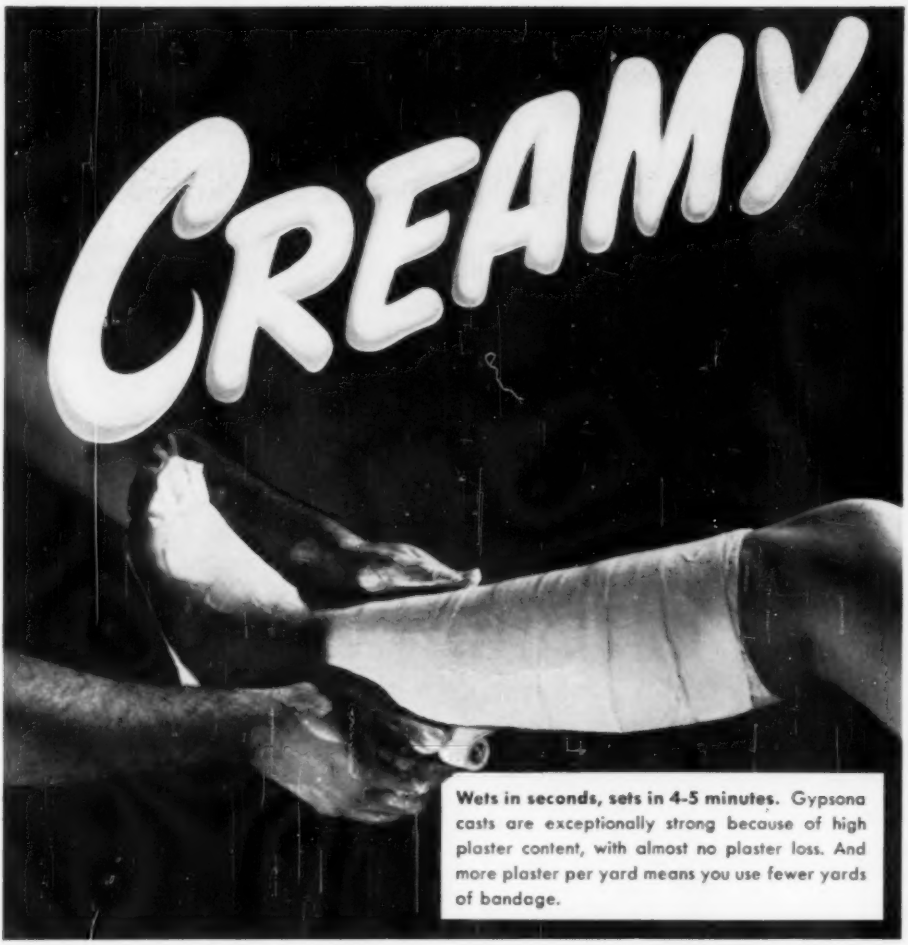

CREAMY
Wets in seconds, sets in 4-5 minutes. Gypsona casts are exceptionally strong because of high plaster content, with almost no plaster loss. And more plaster per yard means you use fewer yards of bandage.

Try Gypsona* with your own hands—here is quality you can feel

The easy workability and precise molding qualities of Gypsona have made it the most widely used plaster bandage in Europe and other parts of the world.

Now Curity makes this quality bandage conveniently available in this country.

Gypsona is made of plaster from a special quarry in England. It is purer, creamier and finer-ground than any other. Plastic core gives easy control to end of roll, will not "telescope." Waterproof package, too.

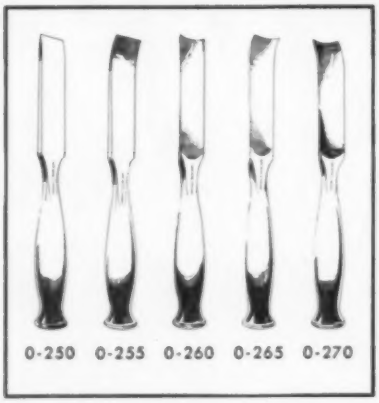
Gypsona casts are lightweight and strong, with a white, porcelain-like finish that stays neat and clean. But do see for yourself—ask your Curity representative for a demonstration.

Curity®
Gypsona
PLASTER BANDAGES
BAUER & BLACK
Division of The Kendall Company

For an appropriately fine cast padding, we direct you to WEBRIL® Bandage

*Reg. T. M. of T. J. Smith and Nephew Ltd.

SMITH-PETERSEN OSTEOTOMES and GOUGES



0-250 SMITH-PETERSEN OSTEOTOME—straight, 8", sizes ¼", ⅜", ½", ⅝", ¾", 1" and 1¼". Stainless Steel.

0-255 SMITH-PETERSEN OSTEOTOME—curved, 8", sizes ¼", ⅜", ½", ⅝", ¾", 1" and 1¼". Stainless Steel.

0-260 SMITH-PETERSEN GOUGE—straight, 8", sizes ⅜", 9/16", ¾" and 1". Stainless Steel.

0-265 SMITH-PETERSEN GOUGE—curved, 8", sizes ⅜", 9/16", ¾" and 1". Stainless Steel.

0-270 SMITH-PETERSEN GOUGE—reverse curved, 8", sizes ⅜", 9/16", ¾" and 1". Stainless Steel.

A NEW STAINLESS STEEL CASE TO HOLD SMITH-PETERSEN OSTEOTOMES and GOUGES

0-295 Open

CASE 0-295—holds seven Smith-Petersen Osteotomes.

CASE 0-296—holds seven Smith-Petersen Gouges.

CASE 0-297—holds a combination of seven Osteotomes and Gouges.

Cutting edges are protected at all times. Complete unit may be autoclaved.

0-295 Closed

Specify Width of Gouges and Osteotomes When Ordering

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American Academy of Orthopedic Surgeons—Feb. 1–6, 1958

"Mediatric" will help make the "senior" years more pleasant and enjoyable.

"Mediatric" is specially formulated to counteract the adverse influence of declining gonadal function, nutritional inadequacy and emotional instability.

"Mediatric" contains estrogen and androgen in amounts that will effectively supplement reduced gonadal hormone production; nutritional supplements carefully selected to meet the needs of the patient; and a mild antidepressant to promote a brighter mental outlook. Available in tablets, capsules, and liquid.

"MEDIATRIC"®

Steroid-Nutritional Compound

IN PREVENTIVE GERIATRICS

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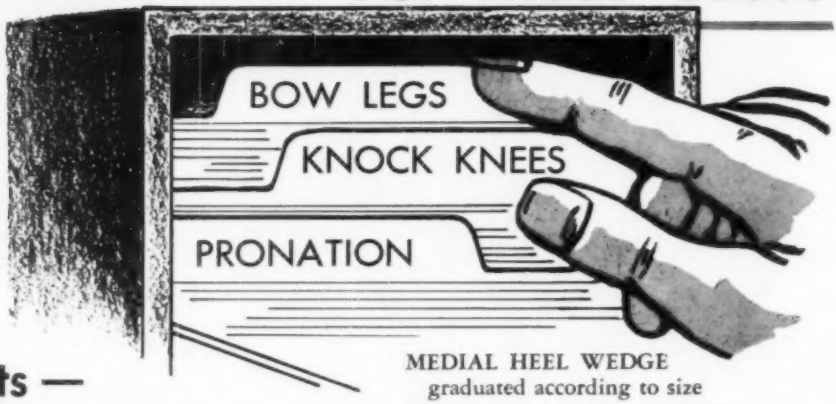
Child Life
ARCH FEATURE SHOES

Most Adaptable For These Cases



Lasts —

CHILD LIFE Arch Feature lasts are made on "Normal Straight Last" lines with allowance on the medial side of the heel to accommodate the basic wedge which is built into the shoe as it is manufactured. The lasts, which have a heel two widths narrower than the ball, are graded in size from AA - EEE; 3½ infant's to misses size 3.

Construction —

Because the shoe is constructed with the basic features listed below, there is need for less additional wedging, and distortion of the shoe is held to an absolute minimum.

GOODYEAR WELT
allows additional wedging

CHROME LEATHER SOLES
finest, best wearing leather

FULL THOMAS HEEL
made of specially compounded rubber

LONG INSIDE LEATHER COUNTER
molded contour for added support

MEDIAL HEEL WEDGE
graduated according to size

RIGHT AND LEFT STEEL SHANK
triple ribbed tempered steel spring

Price —

Because the basic features of the shoe are built-in at the factory, the cost of your adaptation is a small added amount. It means a lower price to the patient and provides many features which could not otherwise be provided — certainly not by a "regular shoe."

Suggested Retail Prices	7.50 —	3½ to 6
	8.50 —	6½ to 8
	9.50 —	8½ to 12
	10.50 —	12½ to 3

Competent Shoe Fitters

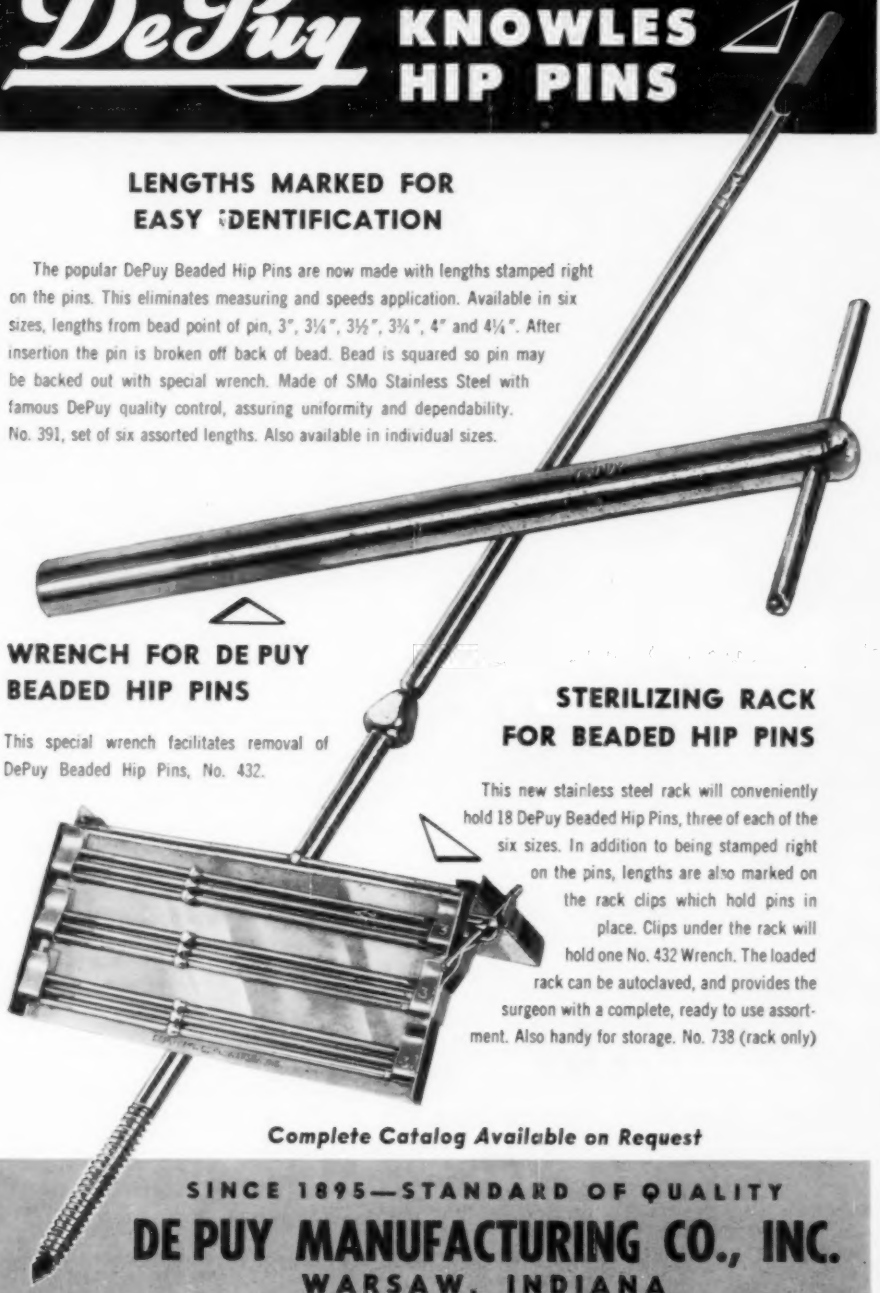
The authorized CHILD LIFE dealer in your community has been selected for his knowledge of shoes and his ability to fit juvenile feet correctly. He is particularly qualified to accept your prescription work, and follow your instructions. Write for his name, and for the CHILD LIFE service booklet for the professional man, featuring representative shoes and wedging procedures.

HERBST Shoe Manufacturing Company Milwaukee 45, Wisconsin

DePuy BEADED KNOWLES HIP PINS

LENGTHS MARKED FOR EASY IDENTIFICATION

The popular DePuy Beaded Hip Pins are now made with lengths stamped right on the pins. This eliminates measuring and speeds application. Available in six sizes, lengths from bead point of pin, 3", 3¼", 3½", 3¾", 4" and 4¼". After insertion the pin is broken off back of bead. Bead is squared so pin may be backed out with special wrench. Made of SMo Stainless Steel with famous DePuy quality control, assuring uniformity and dependability. No. 391, set of six assorted lengths. Also available in individual sizes.



WRENCH FOR DE PUY BEADED HIP PINS

This special wrench facilitates removal of DePuy Beaded Hip Pins, No. 432.

STERILIZING RACK FOR BEADED HIP PINS

This new stainless steel rack will conveniently hold 18 DePuy Beaded Hip Pins, three of each of the six sizes. In addition to being stamped right on the pins, lengths are also marked on the rack clips which hold pins in place. Clips under the rack will hold one No. 432 Wrench. The loaded rack can be autoclaved, and provides the surgeon with a complete, ready to use assortment. Also handy for storage. No. 738 (rack only)

Complete Catalog Available on Request

SINCE 1895—STANDARD OF QUALITY

DE PUY MANUFACTURING CO., INC.

WARSAW, INDIANA

ACTIVE CORRECTION

with lessened need for manipulation, plaster, tenotomy or anesthetics

with

UNITED STATES
Manufacturing Co.

DENNIS BROWN SPLINTS

No torn sheets! Knurled locking nuts and rounded edges prevent damage to bed clothes.

An important improvement in the treatment of club feet, positional deformities, tibial torsions, flat feet, congenital hip dislocations and other deformities that respond to correction by kicking.
Lightweight and strong — made of 24 ST aluminum alloy. Precision adjustment — Positive adjustment by degree angles.
Standard sizes — 6", 8", 12", 14" in stock. 16", 18" and 20" bars available at slight extra cost.

SOLD ON PRESCRIPTION ONLY

You get immediate delivery anywhere when you specify

UNITED STATES *Manufacturing* COMPANY

Pre-fabricated brace parts and orthopedic equipment

NEW ADDRESS! P.O. Box 110 • 623 South Central Avenue • Glendale 4, California
CHapman 5-6855

ready to use just dip, squeeze and apply... requires half as many bandages as ordinary plaster casts

correct drying action no waiting... allows trimming time, then hardens to full strength promptly

makes more comfortable, better looking casts lighter, thinner, smoother... yet much stronger than heavier, clumsier casts of ordinary plaster

makes more durable casts MELACAST retains strength despite humidity, never crumbles or grows soggy... resists water, urine, perspiration, mold... remains odor-free

costs less per cast than plain plaster Specify modern, easier-to-use MELACAST in the new plastic-lined, moisture-proof package... another outstanding SPD development.

*Reg. U. S. Pat. Off.

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AMERICAN CYANAMID COMPANY
SURGICAL PRODUCTS DIVISION
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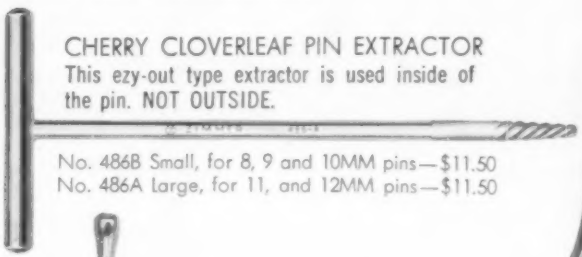
Producers of Davis & Geck Brand Sutures and Vim Brand Hypodermic Syringes and Needles. Distributed in Canada by: North American Cyanamid Ltd., Montreal 16, P.Q.

ADVANCED *Zimmer* Instruments and Appliances for Orthopedic Surgery

No. 825
Schneider self broaching pin $12.75 each

SCHNEIDER **SELF BROACHING** INTRAMEDULLARY PIN . . . . .

- No need for special instruments.
- Prevents rotation of fragments.
- Maximum strength for weight of pin.
- Cuts its own way—less chance of splitting the shaft.
- Larger sized nail can be used for a snug fit.
- May be driven or extracted from either end.
- Less chance of getting out of the groove.
- Grooves allow for free outflow of marrow fat.
- SIZES: 8mm. to 12mm. diameters.



CHERRY CLOVERLEAF PIN EXTRACTOR
This ezy-out type extractor is used inside of the pin. NOT OUTSIDE.

No. 486B Small, for 8, 9 and 10MM pins—$11.50
No. 486A Large, for 11, and 12MM pins—$11.50

"Small Hand Drill"
No. 895
Price $45.00

Lamina Spreader
No. 661
Price $49.50

Zimmer

ZIMMER MANUFACTURING CO. WARSAW, IND.

In Brazil available through Barros, Iskin & Cia, Ltd.,
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In Venezuela: J. D. Colimodio Este 2y Sur 21 No. 148 Caracas, Venezuela

Look for the trademark Ⓩ

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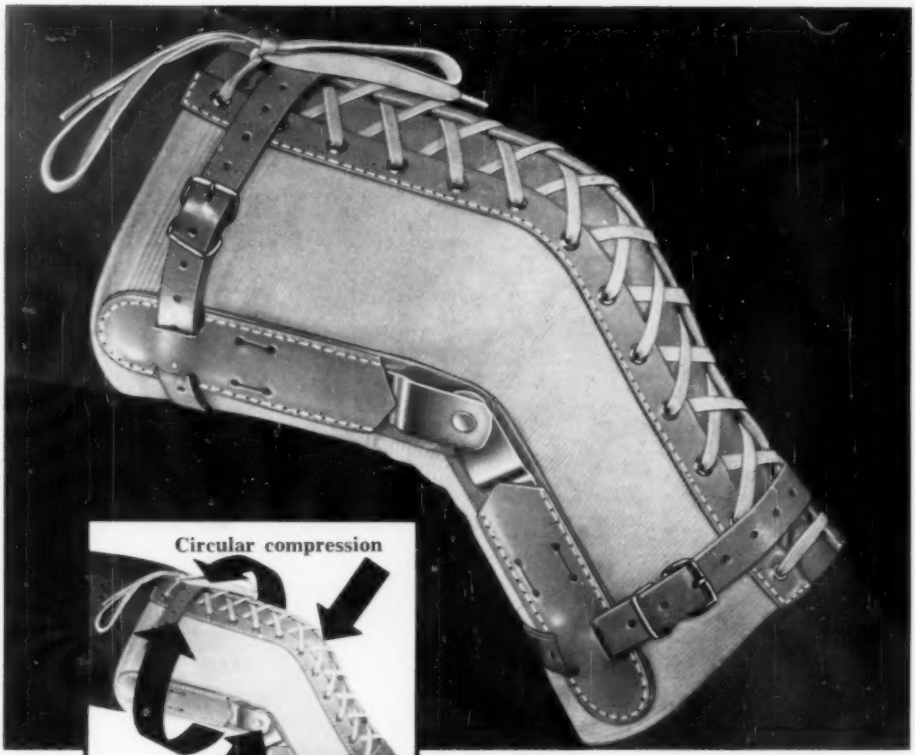


Truform Hinged Kneecaps Model 968 laced front (pictured), Model 969 without lacing, Model 970 without lacing or two encircling straps.

CONTROLLED stability

Circular compression of the entire area covered is readily controlled by adjustment of the lacings . . .

Lateral stability of the joint is effectively controlled by the two leather straps encircling the leg, to which the leather casings of the hinged steel side pieces are joined . . .

Controlled stability is most completely secured with this Truform Hinged Kneecap, another of the anatomically correct and therapeutically sound appliances by Truform.

Truform Anatomical Supports are available to you and your patients only from the Ethical Appliance Dealer.

THERAPEUTIC HOSE

SURGICAL AND POST-OPERATIVE SUPPORTS

CORRECTIVE BELTS AND SUPPORTS

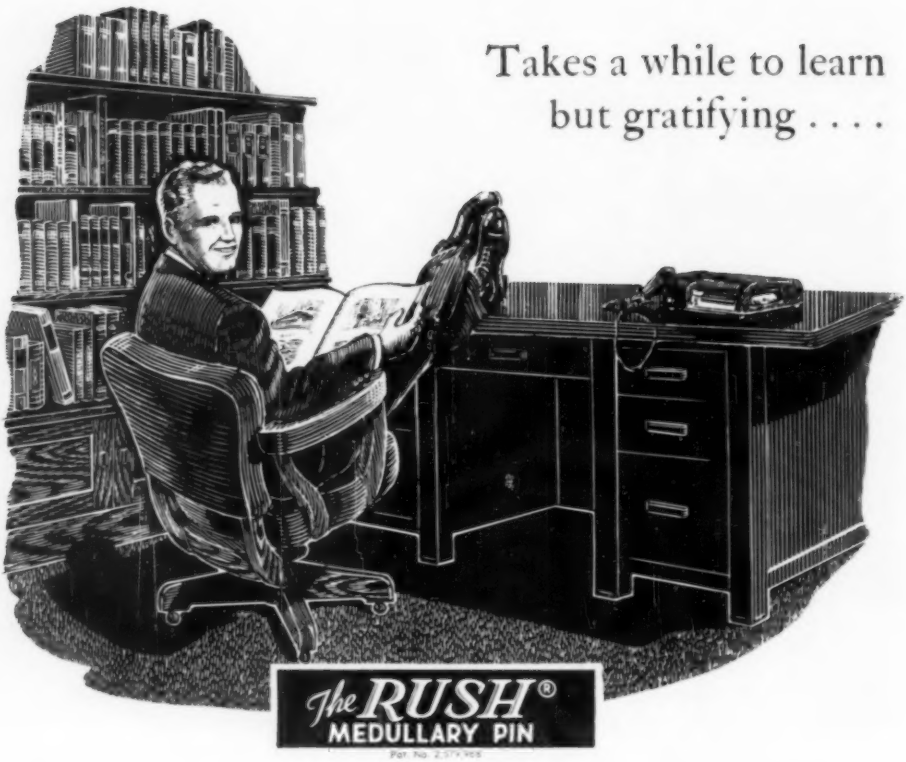
BACK SUPPORTS

Many other types, in many models.
Write for your copy of "The Red Book."

TRUFORM

anatomical supports

3960 Rosslyn Drive, Cincinnati 9, Ohio
BRANCHES: New York and San Francisco



Proper application of the RUSH PIN is not always easy. It takes a while to learn. It is quite different in principle and technic from other forms of medullary fixation. It is not designed to impact the marrow cavity, but to accurately transfix the fractured bone by points of pressure, precisely applied.

The ingenious surgeon, who has added this to his knowledge and skills, has simplified his tasks and contributed pleasure to his patients. He minimizes surgery and speeds convalescence with unbelievably early motion, even in fractures near joints. Removable splints are sometimes used, but casts or traction, rarely.

The patient is more comfortable, the hospital stay is shortened. And best of all, the recovery time and residual disability can be markedly lessened.

It does take a while to learn, but it IS GRATIFYING!

Write for Information

THE BERIVON Company
MERIDIAN, MISS.

EXCLUSIVE MANUFACTURERS OF **RUSH** MEDULLARY PINS AND INSTRUMENTS
Publishers of **"ATLAS OF RUSH PIN TECHNICS"** by LESLIE V. RUSH, M. D.

YOU'LL BE GLAD TO PRESCRIBE

Alden-Pedic

SCIENTIFIC CONSTRUCTION SHOES

Style No. 84

Alden-Pedic lasts and shoes are scientifically designed to fit the individual foot shape and at the same time accommodate your prescribed corrections and insertions without sacrificing any fitting qualities. Alden-Pedic shoes are basic prescription shoes. We do not manufacture a pre-corrected or commercial health shoe.

Orthopedic surgeons familiar with the Alden-Pedic program have achieved most satisfactory results in recommending our shoes.

Write us today for our new illustrated brochure of Alden-Pedic styles for men and boys and our new "Progress Report on Shoe and Last Design".

Developed through our modern research program

- Long inside counter
- Right and left ortho heels, long inside
- Heavy gauge right and left ribbed steel shank.
- New "Depth Design" accommodates prescribed corrections

C. H. ALDEN SHOE COMPANY

Custom Bootmakers Since 1884

BROCKTON, MASSACHUSETTS

FOR BOOKLET AND NAME OF NEAREST DEALER WRITE

marked relief of spasm and stiffness

in a variety of "muscle complaints"...

flexin®

zoxazolamine*

enteric coated • plain

Effective up to 6 hours[1] with a single oral dose, FLEXIN provides gratifying relief of voluntary muscle spasm in low back syndrome, fibrositis, sprains, strains and in non-inflammatory rheumatic and arthritic disorders. Pain and disability are relieved promptly, rehabilitative exercises are more effective and recovery is hastened.

In one study,[2] 85 of 96 patients with various musculoskeletal disorders were improved following the administration of FLEXIN. Forty-one patients experienced excellent relief within 20 to 30 minutes after initiation of therapy and remained symptom-free throughout the day. In 44 others, response was good, and stiffness and aching disappeared within 30 to 60 minutes.

1. Amols, W.: J.A.M.A. 160:742 (Mar. 3) 1956.
2. Smith, R. T.; Kron, K. M.; Peak, W. P., and Hermann, I. F.: J.A.M.A. 160:745, 1956.

PACKAGING

Pink, enteric coated tablets (250 mg.), bottles of 36. Yellow, scored tablets (250 mg.), bottles of 50.

*U.S. PATENT PENDING

[redacted] Laboratories, Inc • Philadelphia 32, Pa.

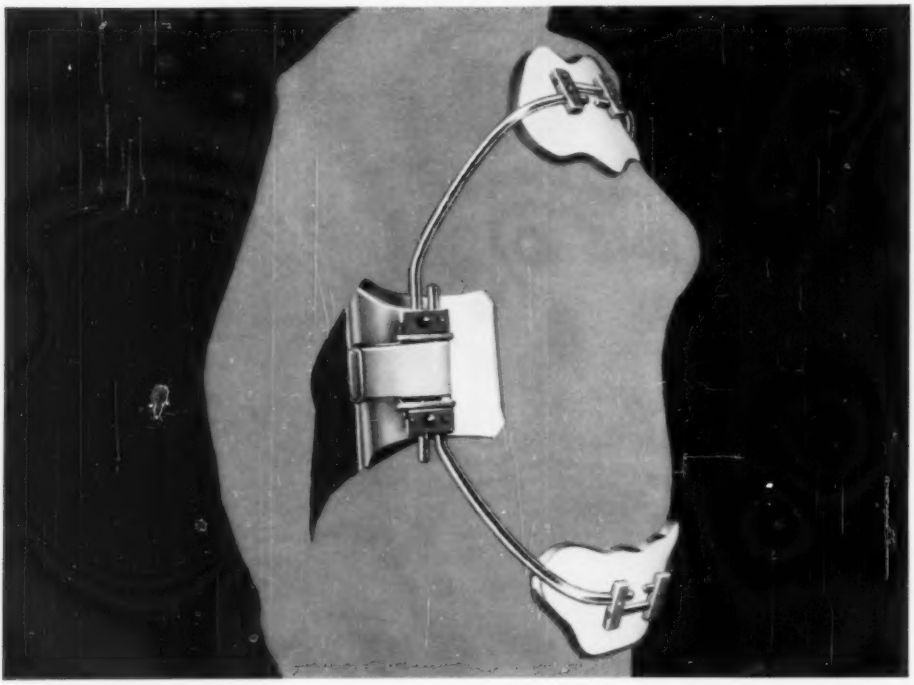
14958

RESPONSE TO FLEXIN (after Smith and others[2])

DISEASE	NO. OF PATIENTS	RESPONSE		PER CENT BENEFITED
		EXCELLENT	GOOD	
Rheumatoid spondylitis	16	8	7	93.7
Fibrositis	34	15	15	88.2
Cervical root syndrome	22	8	11	86.8
Rheumatoid arthritis mild	18	6	9	83.3
Torticollis, acute	2	2	..	100.0
Post-traumatic muscle spasm of low back	3	1	2	100.0
Osteoarthritis of hip	1	1	..	100.0

CAMP HYPEREXTENSION BRACE

positive control with minimum patient discomfort



A Camp spinal brace for positive hyperextension in cases of compression fractures, osteoporosis with kyphosis, spinal arthritis, adolescent epiphysitis and osteochrondritis. Completely rotating pads at sternal and pubic regions eliminate pressure edges and minimize patient discomfort. In many cases the Camp hyperextension brace eliminates necessity for body casts and is definitely indicated in older patients where it is desirable to eliminate the heavy weight of plaster casts and their constricting effect on the abdomen and chest. Telescoping frames allow easy adjustment to the most exacting prescriptions. Camp trained fitters are ready to assist in immediate application.

CAMP TRADE MARK

S. H. CAMP and COMPANY

Jackson, Michigan

In answering advertisements, please mention *The Journal of Bone and Joint Surgery*.

did you know . . .

One of America's Most Popular Brands of Children's Shoes

Poll-Parrot

has a complete line of shoes designed for doctors' prescribed adjustments

Rx

Corrective shoes with a *difference* . . . Vita-Poise by famed Poll-Parrot. All the construction features *you* want for Orthopedic adjustments *plus* expert styling that makes Mother happy. Vita-Poise shoes are developed by skilled specialists, backed by the vast research facilities of America's largest shoemaker. Made on the finest-fitting lasts by experts who know children's *feet* as well as shoes. Pre-Tested by real boys and girls! For doctor *and* patient satisfaction . . . recommend Vita-Poise shoes!

Prescribe your adjustments on a sound foundation **POLL-PARROT** *Vita-Poise shoes with these* **Tru-Guide** *features:*

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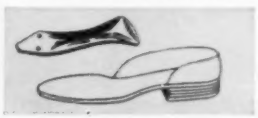

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Central Fractures of the Acetabulum*

BY ROBERT A. KNIGHT, M.D., AND HUGH SMITH, M.D., MEMPHIS, TENNESSEE

From the Campbell Foundation and the University of Tennessee College of Medicine, Memphis

Only in recent years has the attitude of orthopaedic surgeons toward central fractures of the acetabulum begun to change from one of resignation and defeatism to one of aggressive attack. The principles that have been found so important in treating fractures of other joints, particularly the weight-bearing ones, are just as applicable to acetabular fractures: namely, the more anatomical the reduction, the earlier will be the return of function; the more nearly normal the result, the less frequently will degenerative changes develop. More often than not, this ideal can be approached only by open reduction and internal fixation.

In the past, operative reduction of acetabular fractures has been discouraged because (1) the exposure and the reduction have been considered formidable, (2) reposition of so complicated and bizarre an array, or rather disarray of fractures has appeared to be virtually impossible, and (3) the literature is replete with statements that despite a poor roentgenographic result following simple conservative treatment, the functional result (at least for the time being) is always so much better than the roentgenographic appearance would lead one to predict. Further, should the result prove disappointing, or if time and use take their toll, one can always resort to fusion or arthroplasty.

The increasing frequency with which today's automobiles produce this complicated and discouraging situation suggests that orthopaedic surgeons should increase their efforts to find a more satisfactory means of treatment. Current articles, but not the standard texts on fractures, reflect this opinion.

In 1943, Levine described his experience with the open reduction of one patient's acetabular fracture. He approached it from the inner aspect of the ilium and fixed it by means of a metal plate and screws. Urist, in 1949, reported on one patient in whom open reduction of an acetabular fracture was carried out through an anterior iliofemoral approach; the fracture line was so far posterior that the screw had to be inserted through a separate posterior incision. Okelberry, in 1955, reported his experiences with seven patients. He used an anterior iliofemoral approach in all, reduced the fracture by strong lateral traction, and usually fixed it by a single screw inserted obliquely, posteriorly, and medially just beneath the brim of the pelvis and above the acetabulum. He pointed out that more than one screw may be required in comminuted fractures. He was able to obtain a satisfactory result in four patients; but in the other three, the reduction was incomplete and traumatic arthritis developed. The duration of his follow-up studies varied from six

* Read at the Annual Meeting of The American Orthopaedic Association, Hot Springs, Virginia, June 25, 1957.

months to four years. Elliott, in 1956, reported open reduction of central fractures of the acetabulum in three patients. In one, transverse screws were used, while in each of the other two, Hagie pins were inserted from a point above the acetabulum, across the fracture, and down the medulla of the superior ramus of the pubis.

Prior to 1949 at the Campbell Clinic, open surgery in central fractures of the acetabulum was limited to extracting the incarcerated head of the femur from the pelvis when manipulation and traction had failed to do so. Our experience in the open reduction and internal fixation of these fractures began in 1949 with a severely injured nineteen-year-old man (Case 1, Table I). Among this patient's injuries were multiple fractures of the pelvis (Figs. 1-A and 1-B), and ipsilateral fractures of the trochanteric region, shaft, and condyles

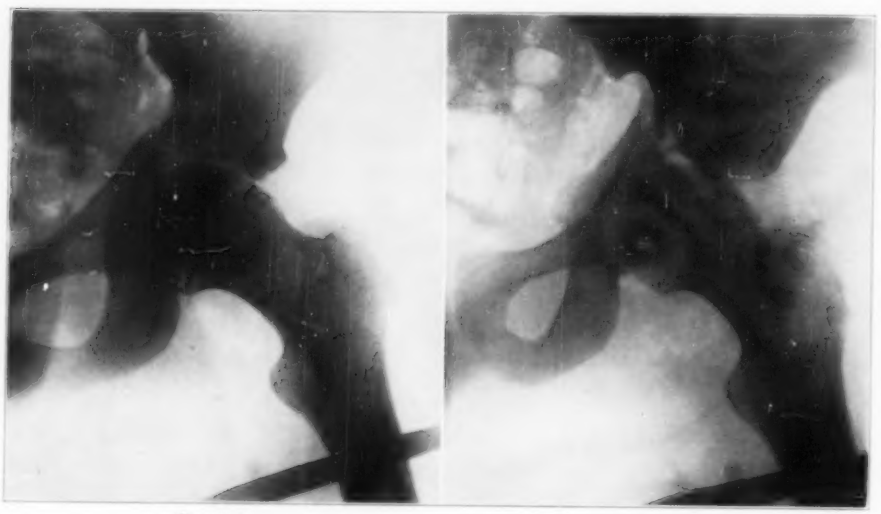

FIG. 1-A FIG. 1-B

Fig. 1-A: Case 1. A horizontal central fracture of the acetabulum, with medial displacement of the femoral head beneath the acetabular vault. Double-dome deformity present. Note also the trochanteric fracture.

Fig. 1-B: The position of the acetabular fragments and of the femoral head has not been improved by traction.

of the femur which precluded the use of the usual methods of traction. The acetabular deformity was so severe that joint junction would be poor, and degenerative changes would with time inevitably develop unless the acetabulum were restored. Open reduction and internal fixation seemed logical. Accordingly, sixteen days after injury, the fracture was exposed through a complete Smith-Petersen iliofemoral approach [6]. The operation, including exposure of the fracture, was difficult; it was almost impossible to close the fracture. Finally, a Knowles pin was introduced into each fragment, one on either side of the fracture (Fig. 2-A). These two pins were then grasped by a bone-holding forceps and the acetabular fragments were forced into near-anatomical position (Fig. 2-B). The reduction was maintained by three Knowles pins inserted across the fracture. All of the patient's fractures united, and now, eight years later, he has made a complete recovery from his pelvic injury with no hip disability (Fig. 3).

Despite the smooth postoperative course and the satisfactory end result in this patient, no further open reductions of central fractures of the acetabulum were performed at the Campbell Clinic until 1955. Since that time we have used this form of treatment in seven more patients—a total of eight. The results have continued to be encouraging, and since we are certain that this is the best method of treatment in properly selected cases,

we therefore present our observations on the subject: the mechanism of injury, the anatomy, the interpretation of roentgenograms, and the method of reduction and fixation.

We want at the outset to point out that it is not possible to restore the acetabulum adequately in every patient, although with further experience the technique will undoubtedly improve. Also, even though a satisfactory acetabulum can be restored, the hip may undergo degenerative changes as a late response to the initial trauma. Regardless, the more perfect the reduction, if obtained without excessive surgical trauma and with minimum disturbance of the soft tissues, the better the outlook for a long-term good result.

For a better understanding of the following discussion, the surgeon should have at hand a skeletal pelvis, stereoscopic roentgenograms of a normal pelvis, and stereoscopic

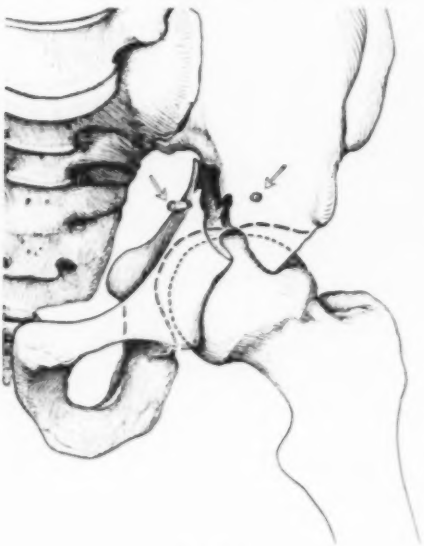

FIG. 2-A

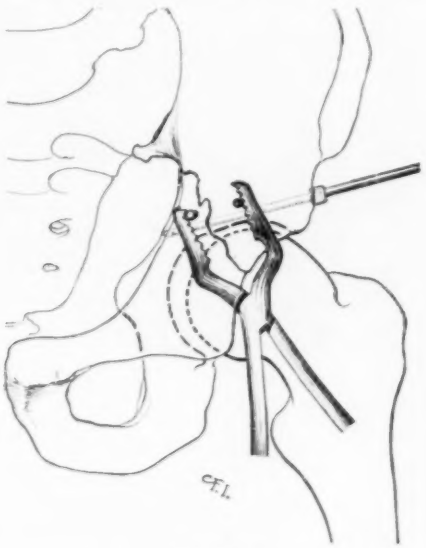

FIG. 2-B

Fig. 2-A: Case 1. This drawing shows the displaced acetabular fracture and the method of inserting the Knowles pins into the ilium on either side of the fracture.

Fig. 2-B: The fracture has been reduced by gripping the Knowles pins with bone-holding forceps. One Knowles pin has been inserted across the fracture.

roentgenograms of a central fracture of the acetabulum. He must develop a three-dimensional image of the pelvis in place of the flat image formed by the usual anteroposterior views. The surgeon must not be surprised if, even after careful study, his preconceived idea of a given fracture does not exactly fit the findings at operation.

We have found it convenient to describe the acetabulum in relation to the face of a clock (Fig. 4): the six-o'clock point is at the center of the acetabular notch, the three-o'clock point is at the posterior margin, and the nine-o'clock point is at the anterior margin. For consistency of nomenclature, the designation is always as if this clock face were superimposed on the left acetabulum. For example, the weight-bearing vault below the anterior inferior spine is at ten o'clock and extends posteriorly to three o'clock. We will continually refer to this clock, and when we say, for example, a "2 to 6 fracture," we mean that the fracture has occurred along the lines denoted by imaginary clock hands pointing at two and at six (Fig. 5).

MECHANISM OF INJURY

The usual concept of the mechanism of an acetabular fracture is as follows: the force of a severe blow to the trochanter is transmitted up through the femoral neck, so that the

FIG. 3

Case 1. Eight years after operation, the result remains excellent. The Knowles pins do not, of course, traverse the hip joint.

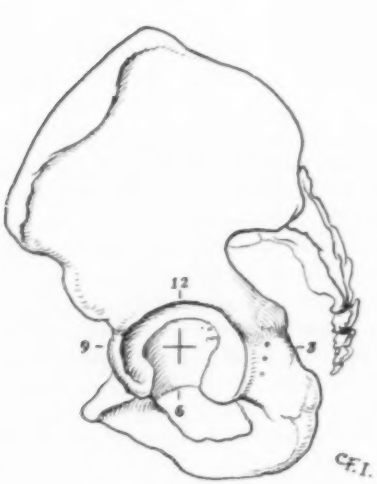

FIG. 4

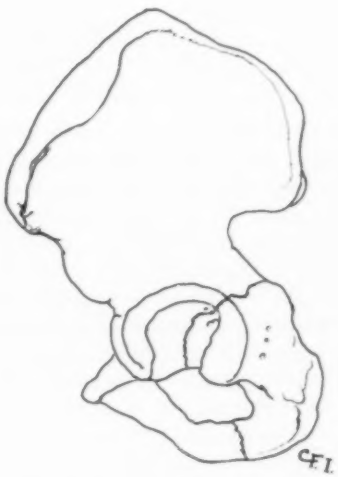

FIG. 5

Fig. 4: The clock. The location of acetabular fracture lines is designated according to their position in relation to the hands of a clock.
Fig. 5: A vertical (2 to 6) central fracture of the acetabulum.

FIG. 6-A

FIG. 6-B

FIG. 6-C

Fig. 6-A: Case 7. A comminuted central fracture of the acetabulum with medial displacement of the femoral head and acetabulum. There is also a vertical fracture extending upward into the ilium from the acetabulum.

Figs. 6-B and 6-C: The result following open reduction. Fixation is maintained by a slotted plate and four screws. Some medial displacement of the acetabulum persists, but the joint is congruous. Note the persisting offset of the vertical fracture extending into the crest of the ilium.

FIG. 7

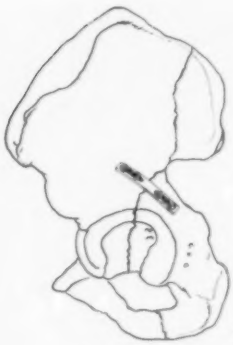

FIG. 8

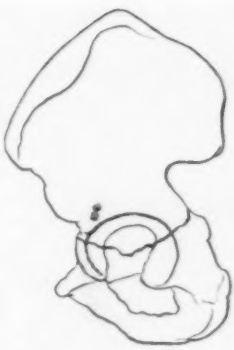

FIG. 9

Fig. 7: A vertical central Y fracture of the acetabulum, complicated by a fracture of the posterior rim of the acetabulum.
Fig. 8: A vertical (12 to 6) central acetabular fracture, fixed by a slotted plate and four screws.
Fig. 9: A horizontal (9 to 2) central acetabular fracture, fixed by two Knowles pins.

head of the femur is rammed through the acetabular wall, breaking the continuity of the arcuate line at nine o'clock. The acetabular fragments and the femoral head are displaced upward and medially. This picture is not wrong, but it is incomplete in both the anatomy of the fracture and the mechanism of injury. The classic acetabular fracture (Fig. 6-A) is seldom found, and the mechanism of injury, a blow on the trochanter, is probably now a rarity.

What follows is now the more frequent, although not the only picture. First, conceive of all the attitudes of the hip that one might assume while sitting relaxed in the right front seat of an automobile, not expecting head-on impact: legs crossed, hips adducted; semi-reclining with hips externally rotated and abducted, and so on. Upon impact, one's knees strike the instrument panel, or one's feet are braced against the floor-board, or one is hurled under the instrument panel to the floor. The innumerable combinations of force through the hip with the femur at varying angles to the acetabulum determine the location and nature of injury. The same mechanism can produce a simple posterior dislocation of the hip if the attitude of the thigh is flexion, adduction, and internal rotation; leverage as well as direct force up the femur contributes to the violence and trauma. The same process occurs in acetabular fractures. Merely change the attitude of the thigh in stages from adduction, flexion, and internal rotation to abduction, external or internal rotation, and less flexion, or even extension, and varying parts of the capsule and the acetabulum will bear the brunt of the blow. The following injuries, in corresponding order, will then result: (a) posterior dislocation; (b) fracture of the posterior rim (3 to 5 o'clock) with posterior dislocation; (c) fractures of the posterior rim and posterior vault (and also 9 to 2 fractures) with posterior dislocation (Fig. 7); (d) 12 to 6 central fracture (Fig. 8); (e) a 9 to 3 central fracture (Figs. 9 and 10-A); and (f) anterior dislocation. A posterior dislocation may occur in conjunction with a horizontal type of fracture (for example, Cases 2 and 5), particularly if there is an associated injury of the posterior acetabular wall *.

Obviously the reverse of these forces—a force against the sacrum or pelvis of a man in knee-chest position, or crawling, or squatting—could produce the same result in a coal-mining accident. Extreme abduction leverage might be the principal force when the fracture is produced by acrobatic dancing (the split) or when one foot remains on a window

* In the series of 123 patients with dislocations and fracture-dislocations of the hip reported by Stewart and Milford in 1954 from the Campbell Clinic, the distribution of injury was approximately as follows:

Posterior dislocation	34 per cent
Posterior dislocation with fracture of the acetabulum	46 per cent
Central fracture of the acetabulum	18 per cent
Anterior dislocation	2 per cent

FIG. 10-A

FIG. 10-B

Fig. 10-A: A horizontal (9 to 3) central acetabular fracture, with the femoral head buttonholed in the pelvis.

Fig. 10-B: Incomplete reduction following manipulation.

Fig. 10-C: The result following skeletal traction. The head of the femur has been brought out into normal relation to the weight-bearing vault, but the fragments of the acetabular floor remain displaced medially. Such fragments rarely follow the femoral head out into position.

ledge while the other is on a painting scaffold moving away from a building.

FIG. 10-C

ANATOMY OF FRACTURE

In our survey of the literature we have found no accurate description of acetabular fractures except Böhler's. In the present series we find nothing typical of the fracture except that there are two or more lines like the hands of a clock traversing the acetabulum. Fortunately, a rather large segment of the ilium at the apex of the acetabulum (approximately 10 or 11 on the clock) is usually intact. This can be utilized as the anchor segment for reconstruction of the weight-bearing vault.

A 2 to 6 fracture involving principally the rim will produce a posterior fracture-dislocation. This injury has been adequately discussed by King and Richards. As the force is directed in the next arc, a more or less vertical 12 to 6 or 1 to 6 fracture may occur; through the next, a horizontal 9 to 3, 9 to 2, or 9 to 1 fracture. The extreme abduction split

FIG. 11-A

FIG. 11-B

FIG. 11-C

Fig. 11-A: Case 2. A horizontal (9 to 2) central fracture of the acetabulum, with 2 to 6 comminution and posterior dislocation of the hip.

Fig. 11-B: The dislocation has been reduced by manipulation. Despite skeletal traction, the "double-dome" deformity of the acetabulum persists.

Fig. 11-C: Appearance one and one-half years after open reduction. The result to date is excellent.

and frog-leg positions which may produce an anterior dislocation, or a 9 to 3 fracture, could fracture the 7 or 8 area, although we have not observed this.

Obviously, these fractures are not straight transverse interruptions of the acetabular continuity. An inverted T or Y arrangement may occur, in which a 6 to 12 limb extends upward to the crest of the ilium (Fig. 6) or backward to the sacro-iliac joint, and may be connected to a 2 to 6 arrangement in which the 2 to 6 portion of the acetabulum is broken into a number of fragments. A 2 to 6 arrangement of fractures may more or less cleanly disconnect the entire proximal ischial segment of the acetabulum.

The horizontal arrangement—9 to 1, 9 to 2, or 9 to 3—may be associated with substantial comminution of the ischial segment of the posterior wall of the acetabulum (Fig. 11-A) but (in all of our cases) presents a serrated oblique fracture anteriorly that can be reduced and fixed anatomically.

The number and arrangement of displaced pieces is bizarre and variable. The femoral head may take a medial course completely through the fracture and be buttonholed by the fragments (Fig. 10-A); or it may lie under the intact vault of the acetabulum despite the extreme displacement of the medial acetabular wall.

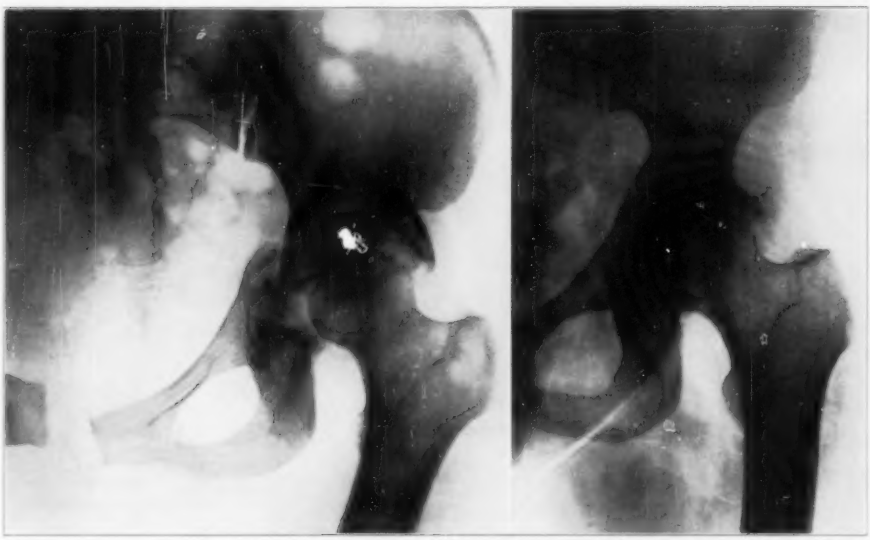

FIG. 12-A FIG. 12-B

Fig. 12-A: Case 5. A comminuted transverse central fracture of the acetabulum, complicated by a fracture of the posterior wall of the acetabulum, posterior dislocation of the hip, and separation of the symphysis pubis.

Figs. 12-B and 12-C: Appearance following open reduction. Function to date is excellent.

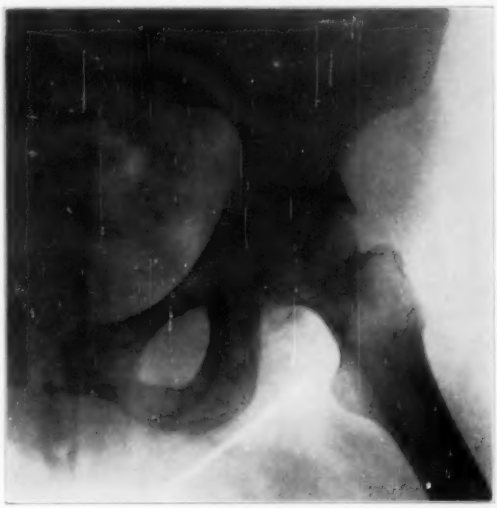

FIG. 12-C

Since the pelvis reacts to a deforming force in the manner of a hoop, there is either a fracture elsewhere in the pelvis, or a sprain, subluxation, or dislocation of the symphysis pubis, or one of the sacro-iliac joints. For example, if the fracture separates the most proximal portion of the ischium from the acetabulum, its medial displacement will usually fracture the other end of the ischium at its junction with the inferior ramus of the pubis.

Further, one should not conceive of the medially displaced fragments as swinging inward on the hinge of another fracture or the symphysis, although this can happen in 9 to 3 arrangements. Rather, the mechanism should be likened to a universal joint capable of rotating in three dimensions. This confusing array of possibilities is understandable when one remembers the innumerable possible combinations of force.

From this chaotic picture, one may yet make a practical classification of these fractures. The major fracture line is either a 12 to 6 arrangement (generally vertical) or a 9 to 3 arrangement (generally horizontal). This is a working rule rather than a truly anatomical classification; it enables the surgeon to select the right surgical approach. To err in this selection may change a normally complicated problem into an unsolvable one. Thus the necessity for the following study prior to surgery.

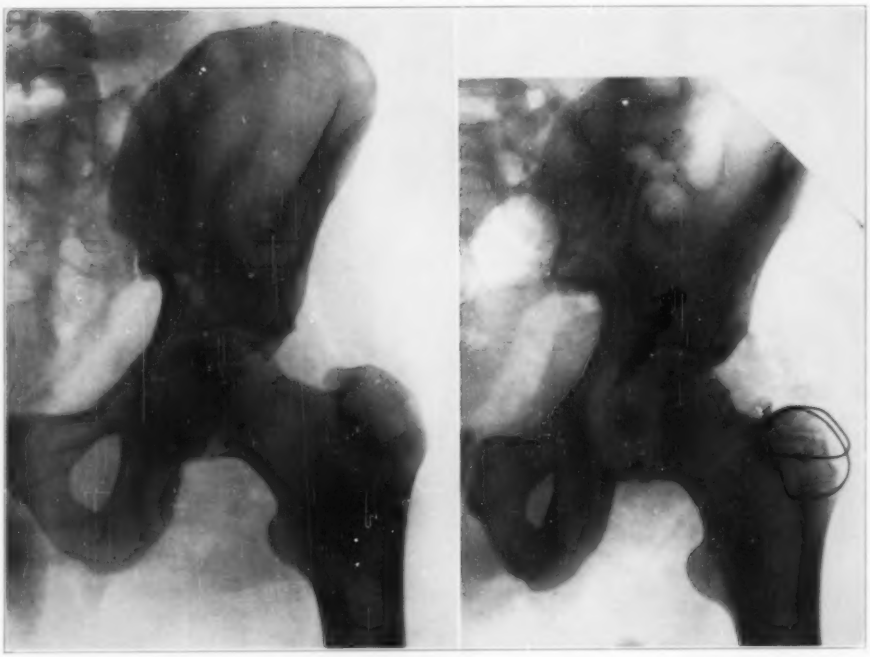

FIG. 13-A FIG. 13-B

Fig. 13-A: Case 4. A vertical (2 to 6) central acetabular fracture, in which the iliac fracture extends upward and posteriorly into the sacro-iliac joint.
Fig. 13-B: The result from open reduction and internal fixation by a plate and four screws.

ROENTGENOGRAPHIC STUDY

In the past, central fractures have usually been studied by means of simple anteroposterior roentgenograms. These do not permit an accurate appraisal of the extent or exact location of the fractures. Theoretically, oblique and lateral roentgenograms of the pelvis should be made, but practically, severe pain and discomfort preclude turning the patient on his side. Stereoscopic anteroposterior roentgenograms are not only a satisfactory substitute for two-plane roentgenography, they are essential.

Correlation of the roentgen anatomy of the pelvis with the gross anatomy begins by replacing the visual images based upon the study of flat plates of the pelvis with three-dimensional visual images of the fracture. Lines with which we are ordinarily not concerned assume importance. In the flat plate, the curved line representing the medial aspect of the acetabulum appears to be a continuation of the edge of the pubis around the inner rim of the pelvis as the arcuate or iliopectineal line (Fig. 16-A). However, if one removes the bone making up the arcuate or iliopectineal line, roentgenograms of the pelvis will reveal little or no loss of continuity. Consequently, this roentgenographic arcuate line in the frontal roentgenogram represents a composite of not only the anatomical structures described above but an edge-on view of substantial segments of the medial part of the acetabular wall and of the edges of the ischium, particularly those that form the body of the ischium and the ischial spine. In plain anteroposterior roentgenograms, therefore, it is virtually impossible to ascertain whether it is the anterior or the posterior portion of the acetabulum which is displaced medially. When the pelvis is correctly positioned for the anteroposterior roentgenogram, the posterior edge of the acetabulum is the more lateral one, but if the pelvis should be rotated, the anterior and posterior lines will overlap or

FIG. 14-A FIG. 14-B FIG. 14-C

Fig. 14-A: Case 8. A vertical (1 to 6) central fracture of the acetabulum, still unreduced seven weeks after injury. A partial sciatic paralysis is present.
Fig. 14-B: The lateral view shows wide separation of the acetabular fragments. The defect is filled with callus.
Fig. 14-C: The early result after open reduction, excision of callus, and fixation of the fracture with a slotted plate and four screws. The function of the sciatic nerve is returning rapidly.

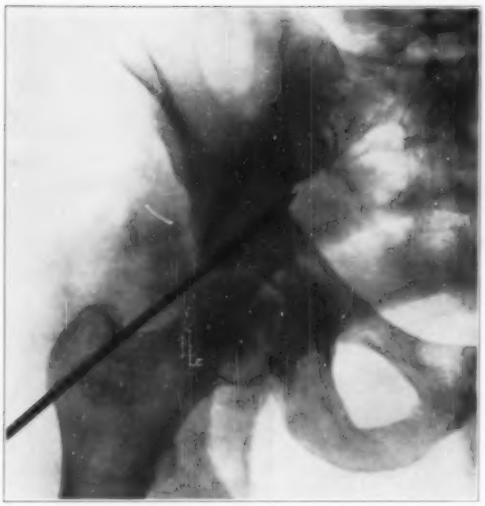

FIG. 15-A

FIG. 15-B

Figs. 15-A and 15-B: A Steinmann pin has been inserted to prevent redislocation of the hip. This form of fixation is useful when the fracture of the posterior wall of the acetabulum is large and comminuted. The patient must be immobilized in a body cast as long as the pin is in place.

reverse their positions. Thus, identification of breaks in anterior or posterior segments of the rim of the acetabulum is not reliable.

The study of a single anteroposterior roentgenogram of the pelvis does provide some information as to the location and type of an acetabular fracture: for example, if the head of the femur lies above and lateral to the intact 10-o'clock vault, the posterior wall of the acetabulum is fractured and displaced and has allowed the head to escape posteriorly to assume a position on the side of the ilium—a posterior fracture-dislocation (Fig. 12-A). The so-called double-dome acetabular deformity (Fig. 1-A) suggests a horizontal fracture, but an almost identical picture (Fig. 13-A) is a vertical fracture. Hasty conclusions from a study of the roentgenograms of the pelvis can thus set the stage for a chastening surgical experience.

INDICATIONS FOR OPERATION

Our experience with central fractures of the acetabulum is not sufficient for us to make hard and fast statements about indications for operation. Long-term studies of large series of patients so treated will be necessary before such statements can be made. But a review of the Campbell Clinic records of patients with such fractures, some with follow-up studies of ten to twenty and more years, leads us to believe that any reasonable effort to restore a congruous acetabulum is worth while except for those patients who are elderly, or obese, or in some other respect a poor risk. The comminution and displacement of fragments, and even of the acetabulum itself, may be such that the surgeon knows from the very outset that the end result will not be an anatomical restoration; yet, if the weight-bearing vault of the acetabulum and its normal relationship with the femoral head can be reestablished, the effort of the surgeon and the risk to the patient is justified.

PRINCIPLES OF RECONSTRUCTION

Perfect restoration of the fractured acetabulum is often impossible, since only one limb of the fracture is usually exposed. Of necessity, the surgeon is therefore limited in what he can accomplish. *The primary objective, however, is reduction and fixation of the fractures which involve the weight-bearing vault (from 10 to 3 on the clock).* Reduction of the defect of the vault is often difficult, for the fracture may be greenstick, the fragments may overlap, or loose bits of bone may lie between displaced fragments. Other mechanical ob-

FIG. 16-A

FIG. 16-B

FIG. 16-C

Fig. 16-A: Case 3. A comminuted vertical central fracture of the acetabulum. Striation of the wing of the ilium is indicative of a vertical extension of the fracture.

Fig. 16-B: The lateral view shows wide separation of the acetabular fragments.

Fig. 16-C: Postoperative appearance. The fractures have been fixed by one screw and one staple. Function is excellent one and one-half years after operation.

structions to reduction may also exist in the opposite or unexposed areas. Should the restored acetabular segment remain displaced medially, the function of the hip can still be excellent if the acetabulum is congruous. If, however, the symmetry of the pelvis can be improved (Fig. 6-B) or restored, so much the better. Otherwise, lengths of the lower extremities may be unequal, and, in women, childbirth may be rendered difficult if the distortion of the true pelvis is severe.

Previous studies of posterior dislocations and fracture-dislocations of the hip have shown that the dislocation of the femoral head must be reduced within twenty-four hours [1,7]. If such a dislocation is associated with a central fracture of the acetabulum (Figs. 11-A and 12-A), the dislocation should be promptly reduced by manipulation and skeletal traction applied; the fracture of the acetabulum is operated upon later. Routinely a period of four or five days should elapse before performing open reduction, so that the patient's condition may be stabilized. As many as two or even three weeks may elapse after injury, and yet open reduction still be carried out. One patient (Case 8, Table I), initially treated elsewhere, was operated upon seven weeks after injury (Figs. 14-A, 14-B, and 14-C). The procedure, as expected, was more difficult and required a much more extensive dissection than if it had been performed earlier.

The type of fracture and the approach through which the reduction can be most

TABLE I

Patient	Age	Sex	Date of Injury	Type of Fracture	Fig. Nos.	Other Injuries	Preliminary Treatment of Hip	Date of Operation	Surgical Approach
1	19	M	Aug. 27, 1949	9–3	1-A, 1-B, 2-A, 2-B, and 3	Multiple ipsilateral injuries	None	Sept. 12, 1949	Anterior
2	39	F	May 28, 1955	9–2 with 2–6 comminution	11-A, 11-B, and 11-C	Posterior dislocation of hip; partial sciatic nerve injury	Immediate reduction of dislocation; skeletal traction	June 7, 1955	Anterior
3	17	F	Jan. 1, 1956	1–6 with comminution	16-A, 16-B, and 16-C	Fracture of humerus; foot injury	Manipulation Jan. 3, 1956	Jan. 6, 1956	Anterior (should have been postero-lateral)
4	28	M	June 25, 1956	2–6	13-A and 13-B	Severe compound fracture of elbow	Skeletal traction	July 3, 1956	Postero-lateral
5	38	F	July 8, 1956	9–4 with 1–4 component	12-A, 12-B, and 12-C	Posterior dislocation of hip; compound fracture of both bones of forearm	Immediate reduction of dislocation; skeletal traction	July 20, 1956	Anterior
6	15	F	July 30, 1956	9–3	No roentgenograms	Ipsilateral ankle fracture; severe facial injury	Skeletal traction	Aug. 17, 1956	Anterior
7	23	F	Dec. 23, 1956	12–6, with 9–3 component	6-A, 6-B, and 6-C	Facial injuries	Skeletal traction	Jan. 9, 1957	Postero-lateral
8	27	F	Apr. 6, 1957	1–6	14-A, 14-B, and 14-C	Compound knee injury and fracture of external tibial condyle, ipsilateral; partial sciatic nerve injury	Immediate skeletal traction, discontinued 5 weeks later	May 29, 1957	Postero-lateral

effectively carried out must be determined preoperatively. In the horizontal fracture (9 to 3), the defect should be closed through an anterior approach. The anterior iliofemoral approach which Smith-Petersen developed for mold arthroplasty [6] affords a very satisfactory exposure of such fractures. The iliacus muscle is elevated from the inner surface of the ilium and the psoas tendon is, if necessary, divided. The gluteal muscles are stripped from the outer surface of the ilium sufficiently to expose the ilium above and anterior to the acetabulum, permitting insertion of the transfixing Knowles pins or screws. The fracture cannot be drawn into final position by the lag effect of the threaded pin or screw. Rather, the fracture must be reduced first and then fixed. Pins and screws must traverse the cortex on both sides of the fracture. Threads engaging only the cancellous bone of the pelvis may not hold, for there is considerable tension on the fixative agents after reduction. We have not had occasion to place a plate and screws along the iliopectineal region of the pelvis as Levine did, but the bone here is thick enough to do so if advisable. If, in addition, the posterior wall of the acetabulum is comminuted, and there is danger of redislocation or subluxation, a transfixing Steinmann pin (Figs. 15-A and 15-B) may be drilled through the greater trochanter above the level of the femoral neck, and into the ilium just above the acetabulum. The patient is then either immobilized in a body cast or skeletal traction is maintained for six to eight weeks. Weight-bearing is permitted after ten to twelve weeks.

For the vertical (12 to 6) fracture, the defect of the apex of the acetabulum should be reduced and fixed through a posterolateral approach [5]. Should the fracture extend vertically from the acetabulum up toward or even through the iliac crest (Figs. 6-A and 6-B), it may be necessary to extend the subperiosteal dissection of the gluteal muscles sufficiently to permit adequate exposure of the proximal limb of the fracture. In other instances, the fracture may extend further upward and then backward toward the sacroiliac joint (Fig. 13-A) or the greater sciatic notch (Fig. 14-A). Here again, posterior dissection will be required.

The vertical type of fracture is harder to reduce than the horizontal type because it is so deeply situated within the incision and because the smooth, relatively flat surfaces of the fragments cannot be grasped by ordinary bone-holding instruments. Knowles pins drilled into the fragments can be used to manipulate them up into position. The depth of the fracture does not ordinarily permit the use of transfixion screws. In such instances, staples (Fig. 16-C) or slotted plates and screws (Figs. 8, 13-B, and 14-C) are inserted into the thick bone above the acetabulum. When the deforming force is considerable, the slotted plate has the added advantage of permitting impaction of the fracture just before the screws are finally tightened. If there is an additional posterior acetabular fragment, it may be fixed in place with screws in the same manner as in reduction of an ordinary posterior fracture-dislocation.

It is not usually necessary to incise the capsule of the hip joint to be certain that the acetabular fracture is accurately reduced. In horizontal fractures, the capsule may be opened if the surgeon fears that a fragment of bone may be lying free in the joint; otherwise, the anatomical reduction of the fracture at the iliopectineal line is sufficient evidence that the congruity of the joint has been restored. In vertical fractures, the glenoid labrum may be dissected from the superior margin of the acetabulum for a short distance on either side of the fracture so that the bone edges may be visibly matched. The surgeon is then assured that the acetabular portion of the fracture is reduced.

RESULTS

We cannot, of course, speak of end results in this small series of patients. The significant matters about them to date, in regard to their injury and our method of treatment, are summarized in Table I. The early return of motion, without pain, is in sharp contrast to the slow return of motion and function which usually follows the use of heavy skeletal traction and traction body casts.

CONCLUSIONS

1. Open reduction of central fractures of the acetabulum is technically feasible. The primary objective is to restore the weight-bearing vault. Improvement of symmetry of the pelvis or reduction of the posterior portion of the acetabulum, if achieved as well, is a dividend.

2. Detailed classification of these fractures is neither possible nor necessary. A simple working rule divides them into two major types: horizontal, and vertical. The horizontal type is approached through an anterior incision; the vertical, through a posterolateral incision.

3. Stereoscopic anteroposterior roentgenograms are essential to the correct interpretation of the fracture and to the correct choice of approach.

4. Following open reduction, after-care is greatly simplified, and morbidity is greatly diminished.

5. The results after open reduction are, to date, generally superior to those obtained in the past by the older methods of manipulation and traction.

6. Long-term studies of large series of patients will be necessary before the method can be fully evaluated.

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DISCUSSION

Dr. Carter R. Rowe, Boston, Massachusetts: Dr. Knight and Dr. Smith go directly to the crux of the problem of central acetabular fractures in their paper. They point out:

1. The importance of careful and complete roentgenographic study;
2. The significance of the superior acetabular weight-bearing surface in relation to prognosis;
3. The careful planning of surgical approach before it is attempted;
4. The principle of anatomical reduction to a weight-bearing joint.

Their advice that the fractured acetabulum should be reduced as accurately as possible is sound. The difficult decision to make is which patients should have open reductions and which should be treated by closed methods.

I agree with the authors that the most reliable indicator is the superior weight-bearing quadrant of the acetabulum. Follow-up studies in our patients showed that the good and excellent results were in those patients with an intact superior quadrant in good relation to the femoral head. The poor results were in those in whom the superior quadrant was not, or could not be reduced, or the femoral head could not be brought under the superior shelf and held there. There were other factors also which affected prognosis, such as, stability of the joint posteriorly, roentgenographic evidence of injury to the femoral head, and loose bone fragments in the joint. Residual incongruity of the medial and inferior acetabular quadrants seemed to have little effect on prognosis.

As Dr. Knight and Dr. Smith point out, careful roentgenographic study is essential. Anteroposterior views can be most deceptive. Stereoscopic views are very helpful, but we need good views taken of the superior and posterior aspects to determine the exact position of the displaced fragments.

There seems to be a growing pessimism for closed treatment of severe central acetabular fractures. There

(*Continued on page 60*)

The Küntscher Method of Intramedullary Fixation *

BY GERHARD B. G. KÜNTSCHER, SCHLESWIG-HESTERBERG, SCHLESWIG, GERMANY

Intramedullary nailing represents the ideal treatment of fractures and requires no external fixation or special postoperative care.

The basic principle in this method is stable osteosynthesis through flexible impingement of the nail in the bone. The nail must be wide enough to occupy the entire cross section of the medullary canal and to bear the body weight and the stresses of the musculature. Even in fresh fractures this will frequently require the use of reamers to widen the medullary canal over its entire length. This method will guarantee success. Failures will occur only if the basic principle is not followed. The application of this method is not limited to fractures or pseudarthroses in long, hollow bones; it also has its advantages when used following such procedures as osteotomy and arthrodesis.

Through experience and improvements, it has been possible to minimize the dangers and disadvantages of this method.

During recent years scientific research has given us a clear understanding of what takes place at the fracture line during healing of the bone. We know that callus is extremely sensitive to mechanical stresses and can only develop when complete mechanical rest prevails. Pushing, twisting, and pulling forces will destroy it and so will weight-bearing stresses, because the callus has little mechanical strength and insufficient elasticity.

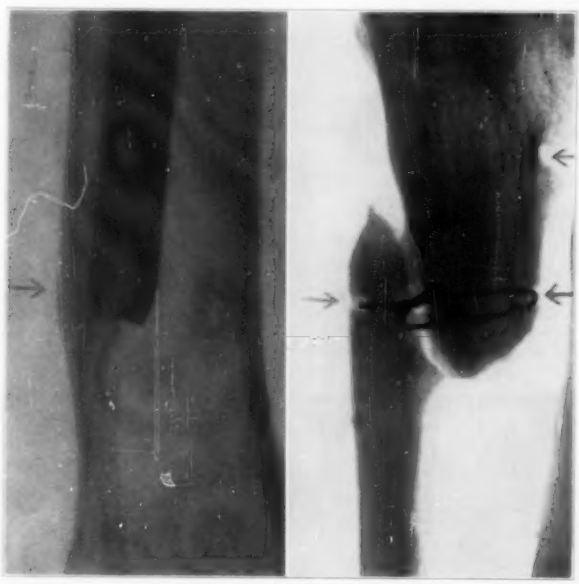

FIG. 1

Roentgenograms showing two different methods of fixation: *right*, circumferential wiring (stainless-steel wire) and, *left*, intramedullary nailing (stainless-steel nail). In the case in which wiring was done, bone atrophy developed; in the other case there was considerable thickening of the cortical wall where the top of the nail pressed against it.

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 31, 1957.

Therefore, any method of treatment of fractures should aim at complete immobilization of the fragments throughout the healing process. Methods of external splinting, such as plaster casts, certainly cannot accomplish this satisfactorily, because within the soft parts, such as the muscles and fatty tissue, the fragments are still capable of considerable motion. The splint must be fitted directly to the bone! Such an inner splint should be inserted into the medullary canal and not be affixed to the outside of the bone; otherwise, it will damage the periosteum, which plays a major role in callus formation and bone nutrition. Outside pressure on the bone will cause atrophy, while inside pressure will result in thickening of the bone, as shown in Figure 1.

It is evident that circumferential wiring applied to the outside of the bone causes atrophy but that a nail inserted into the medullary canal with its tip pressing against the cortical wall has the opposite effect, namely, it promotes bone growth. The correct method, therefore, is intramedullary fixation. Intramedullary fixation is the method of the future. At the same time it is anything but new. During World War I, for instance, Prof. Hey Groves inserted solid metal rods or nails of a cross design into the medullary canal. Schöne treated fractures of the forearm with flexible silver pins, and Lambrinudi used Kirschner wires for the same purpose. None of these methods found acceptance, however, and they were either forgotten or discontinued as unreliable by their originators.

It was the introduction of the principle of elasticity which finally brought success. Two basically different methods of intramedullary fixation must be distinguished, namely,

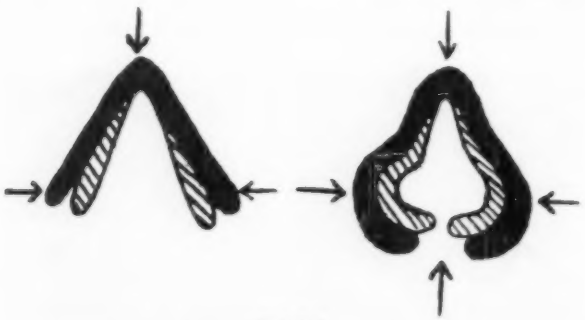

FIG. 2-A

Drawings showing cross sections of two types of intramedullary nails. The V nail is compressible in only one direction, whereas the clover-leaf nail is compressible in two directions, these directions being at right angles to each other.

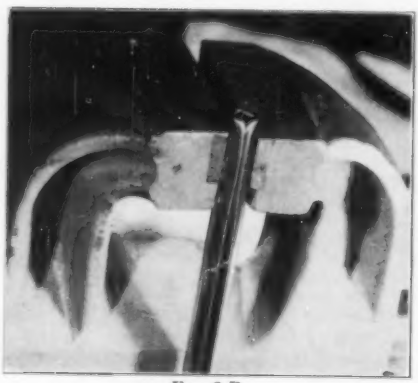

FIG. 2-B

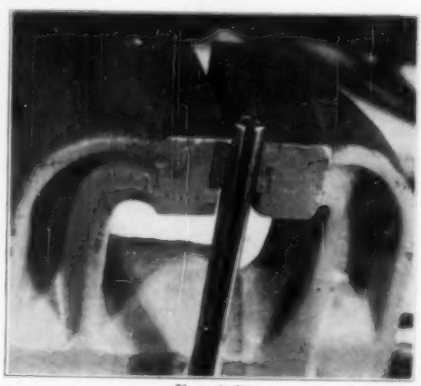

FIG. 2-C

the use of a pin and the use of a nail. I do not intend to elaborate on the first method which was developed by J. and L. Rush and which was perfected by these men until it was satisfactory for the treatment of most fractures. Instead, I want to concentrate exclusively on the other procedure, intramedullary nailing. This involves not only longitudinal elasticity, as in the Rush pin, but also elastic compressibility in cross section.

I have deliberately chosen the term *nail* to describe the intramedullary appliance, for this device becomes firmly impinged in the bone by elastic forces in the same way that a carpenter's nail becomes impinged in wood. It is firmly seated and cannot easily be turned or retracted. The analogy does not follow in every detail, however. In cross section a carpenter's nail is almost completely rigid, and when it is driven into wood, it pushes the wood aside. It is the elastic wood material which firmly grips the nail. By contrast, the cross section of the medullary canal is quite rigid and will split apart if stretched only a few hundredths of a millimeter; therefore, to achieve elastic impingment, the cross section of the nail itself must be designed to have elasticity. This cannot be accomplished with a nail that is solid in cross section or with a nail that has a cross design but requires a nail with a V profile or, even better, a nail with a clover-leaf design which is compressible in two directions (Fig. 2-A). A simple experiment demonstrates the elastic compressibility of the clover-leaf nail: if a clover-leaf nail twelve millimeters in width is mounted into a vise, it can be compressed about three millimeters but will immediately recover its original shape when released from the vise, as shown in Figures 2-B and 2-C.

Use of this principle of elasticity will achieve the ideal of complete and permanent immobilization of the fragments and offers an absolute guarantee of bone union. There are two reasons for this:

1. It is obvious that lateral movement can be eliminated only if the nail occupies the entire width of medullary canal throughout most of its length. This cannot be accomplished with a solid rod which cannot be compressed, for the medullary canal varies in width and the solid nail must be selected to fit the narrowest portion. When an elastic nail is inserted, however, it will be compressed in the narrow portions but will still be able to span the wider parts (Fig. 3).

2. The second reason is also of great importance. Bone resorption will occur about any foreign body and will soon loosen a solid rod, even though at first this rod may have accurately fit the width of the canal. A nail with a compressible cross section, however, will expand during bone resorption. This nail is designed to render the mechanical effects of bone resorption ineffective and represents the only means to meet this problem (Fig. 4).

FIG. 3

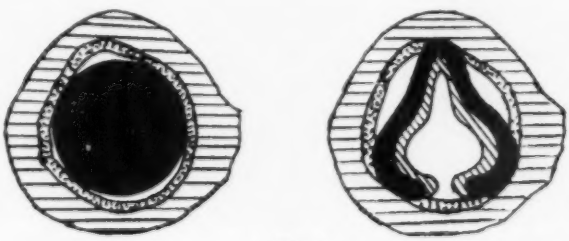

FIG. 4

Fig. 3: A solid nail (*left*) will not occupy the full width of the medullary canal in most places since its diameter must be selected to fit the narrowest portion of the canal. A nail with an elastic cross section (*right*) will adjust to the constrictions of the medullary canal.

Fig. 4: A solid rod (*left*) is loosened by bone resorption. The elastic property of the intramedullary nail (*right*) counteracts the mechanical effects of bone resorption, however, with the result that this nail remains firmly seated for a long time.

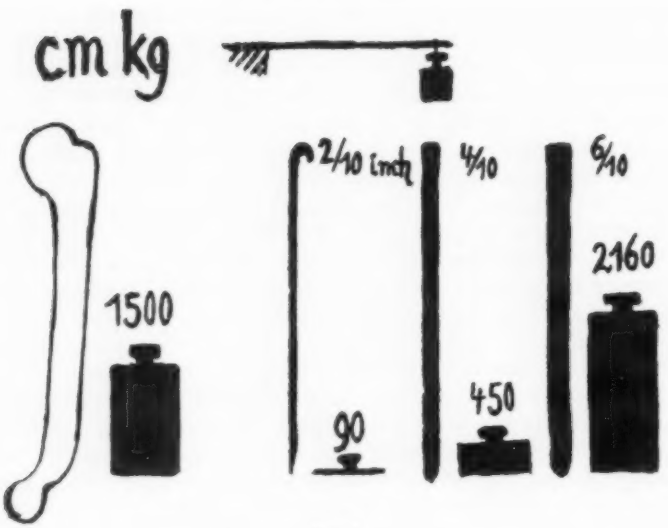

FIG. 5

Comparative resistance to bending force of a normal humerus and of appropriate intramedullary rods of varying widths.

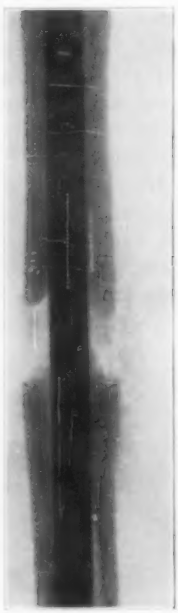

FIG. 6-A

FIG. 6-B

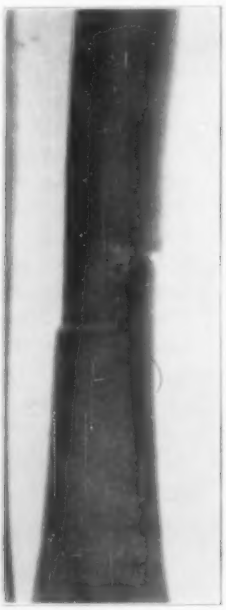

FIG. 7-A

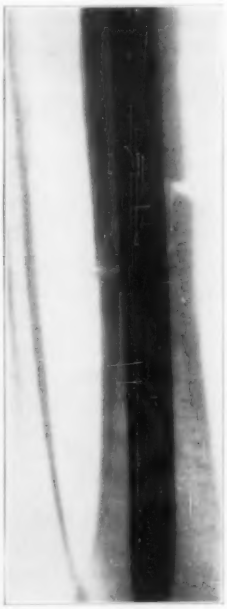

FIG. 7-B

Figs. 6-A and 6-B: Roentgenograms showing a humeral fracture in a man, twenty-six years old. The fragments were driven apart by the insertion of a twelve-millimeter intramedullary nail. Elastic impingement was so strong that despite immediate and continued intensive muscle action, the gap remained 1.8 centimeters wide and became filled with callus.

Figs. 7-A and 7-B: Roentgenograms showing a tibial fracture in a thirty-year-old man. In order to insert a strong intramedullary nail, it was necessary to ream out the entire medullary canal, changing its width from five millimeters to twelve millimeters. Following this, stable osteosynthesis was obtained.

The nail remains firmly seated for an extended period of time and thus meets the requirement that it be absolutely immovable during the entire duration of the healing process.

A certain longitudinal elasticity is also required, for long, hollow bones are not straight. The femur, for example, is slightly bent anteroposteriorly.

Another important factor that must be considered is that the splint is subjected to extremely heavy stresses. In all muscle action, tremendous forces amounting to several hundred kilograms are brought into play, for both protagonists and antagonists work simultaneously. The nail must therefore be able to withstand great mechanical stresses. This is possible only by using very good steel and by using the best type of cross-section design. A nail of insufficient width does not have the necessary strength to withstand the muscle stresses. It will either bend or break. This becomes clear through comparative tests. Figure 5 demonstrates both the bending force which a normal humerus is able to withstand and the bending factor of several strong nails. Despite the fact that the enormous strength of bones cannot be easily duplicated by artificial means, the bending factor of an intramedullary nail twelve millimeters wide is considerably greater than that of the humerus for which it is an appropriate size.

In order to achieve the greatest possible stability, it is advisable to use the longest nail possible. By this means the entire length of the medullary canal may be exploited for purposes of mechanical retention.

If all these factors are observed, it is possible to achieve such complete immobilization of the fracture line that the severest stresses will be withstood for the entire duration of the healing process. The callus will thus be able to develop under conditions of complete rest, a circumstance which will absolutely guarantee bone union of the fragments. That such stable osteosynthesis is actually possible is demonstrated by the following case history. The patient was a man, twenty-six years old, with a fractured humerus. A twelve-millimeter intramedullary nail was inserted into the humerus from the proximal end. The nail was driven in by means of a 1000-gram hammer under such great force that it pushed the fragments 1.8 centimeters apart. The extremely muscular patient was asked to resume immediately unrestricted movement of his arm, in the hope that muscle pressure would push the bone ends together. This did not occur, however. As Figures 6-A and 6-B show, the gap remained unchanged but became filled

FIG. 8-A

FIG. 8-B

Fig. 8-A: Roentgenogram showing a pseudarthrosis in the ulna. The medullary canal was reamed to such an extent that only a thin layer of bone and periosteum remained.

Fig. 8-B: Eight weeks after the insertion of a nail, the thickness of the cortical wall was normal again as a result of regeneration.

with callus. This proves that throughout the entire healing process elastic impingement was so strong that it could withstand the enormous stresses of the musculature.

This case demonstrates that, in spite of what many authors claim, no pressures are needed to stimulate callus formation. It shows that callus develops just as well when the fragments are apart as when they are in close apposition. In every case in which stable osteosynthesis is achieved by means of the intramedullary nail, the callus will consistently form a bone bridge, even if the extremity is immediately subjected to strong, unrestricted muscle action.

Any additional external splinting such as use of a plaster cast is not only meaningless but harmful! It is one of the invaluable advantages of this method that it eliminates the dangers of immobilizing the joints and muscles and prevents local and general circulatory disturbances. We have encountered no joint stiffness and have not even seen the feared and persistent oedema of the shank which always attends the use of a plaster cast. The patient can soon leave the hospital to return to his family and his work. In cases of fracture of the lower limb, ambulation and weight-bearing will be possible after an average of

FIG. 9-A FIG. 9-B FIG. 9-C

Fig. 9-A: Fracture of both bones of the forearm treated by intramedullary nailing. A nail of adequate width was used in the ulna and the fracture healed properly. The nail used in the radius was too thin, however, and pseudarthrosis developed.

Fig. 9-B: Healing of the radial pseudarthrosis was obtained without difficulty by removal of the nail, reaming of the canal, and insertion of a stronger nail.

Fig. 9-C: Roentgenograms showing the final results after removal of the nails.

eight to ten days. Elderly people are even allowed to be out of bed on the day of surgery in order to prevent the dangers of pneumonia and circulatory disturbance. Intramedullary nailing is an ideal treatment of fractures in that it requires no special postoperative care. Joint stiffness and circulatory disturbances will not occur and therefore do not have to be treated. No massage or other measures are needed; indeed, they are even harmful, because they make the patient more conscious of his injury. The psychological factor also plays an important role in the treatment of fractures!

If a pseudarthrosis occurs or if the nail bends or breaks, it is primarily for one reason: the size of the nail used is incorrect. If the nail is too small, it cannot achieve immobilization because it will not be sufficiently impinged in one or even both of the fragments; on the other hand, if it is too thin, it cannot withstand the mechanical stress of the muscles. A second cause of failure which is much rarer is that the method is unsuitable for the particular patient. For example, if there is extensive damage or if the fracture is near the joint, the nail will not provide stable fixation. The underlying cause of all failures is the same, however: no stable osteosynthesis has been achieved. In all instances the surgeon, not the method, should be blamed.

There are many cases in which a few portions or even the entire length of the medullary canal are so narrow that an intramedullary nail of adequate width cannot be inserted. In one case, for example, there was a local constriction of eight millimeters in the medullary canal of the femur just below the lesser trochanter. In this case, following removal of the constriction by means of a reamer, a twelve-millimeter intramedullary nail could be inserted. Reaming of the medullary canal is the final but most important step in intra-

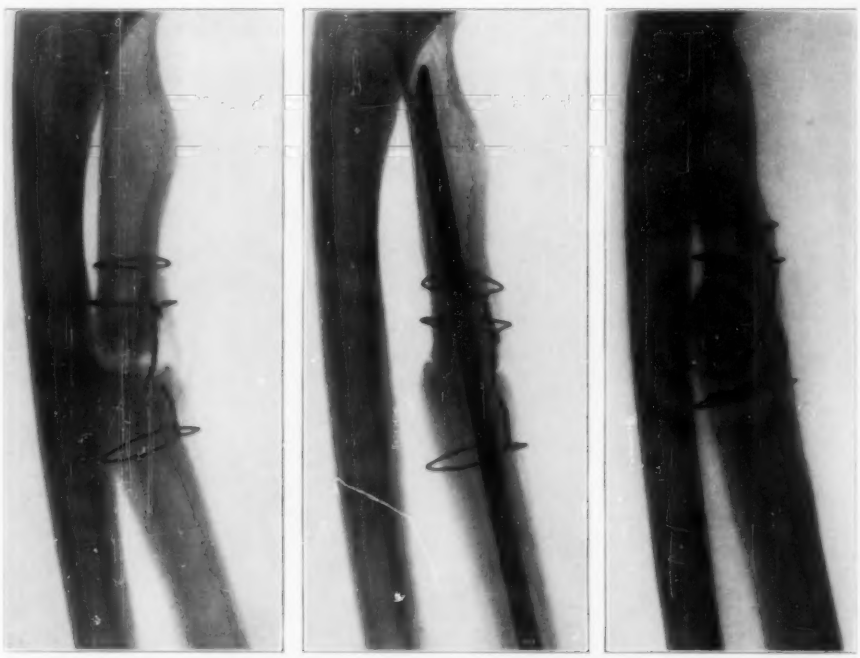

FIG. 10-A FIG. 10-B FIG. 10-C

Fig. 10-A: This roentgenogram shows a pseudarthrosis of the forearm which had been present for five years. Treatment by wiring had been unsuccessful.

Fig. 10-B: Healing was obtained by reaming and intramedullary nailing without exposure of the fracture site.

Fig. 10-C: Final result after removal of the nail.

medullary nailing. In many cases, such as in cases of fracture of the forearm, the operation is inconceivable without this procedure.

The medullary canal is reamed out over its entire length. Although the diameter of the reamer used corresponds exactly to that of the nail, elastic impingement is nevertheless assured. The reason for this is that the canal cannot be reamed out to a true cylindrical shape since the tip of the reamer will describe an imaginary spiral. Because elastic impingement is assured in this way, intramedullary nailing is indicated even in cases in which the nail's cross section will not suffice to span the widest portions of the medullary canal. Reaming will remove the constrictions, making it easy to insert a nail of sufficient width. If the entire medullary canal is too narrow, it is simply reamed out until it is wide enough to receive a nail sufficiently wide to withstand the muscle stresses. This approach is preferable to using a nail which does not require any reaming at all, for following reaming the nail will be more or less evenly engaged throughout the medullary canal instead of being engaged in only a few narrow portions. Figures 7-A and 7-B show a fracture of the tibia in a thirty-year-old man. At the fracture line and in the distal third of the tibia, the medullary canal had a width of eleven millimeters, while at the proximal end it was only five millimeters wide. The medullary canal was widened with a reamer throughout its entire length until a twelve-millimeter intramedullary nail could be inserted. This procedure made stable osteosynthesis possible, and the patient was allowed to begin weight-bearing eight days later.

Undoubtedly the intramedullary-nailing method constitutes a most daring approach, and the question arises whether we can safely follow it. It is certain that this operation will destroy the nutrient artery, but in how many cases is it not torn or broken without knowledge anyhow? The endosteum is also completely destroyed, not to mention the bone marrow which is completely removed. However, my extensive animal experiments

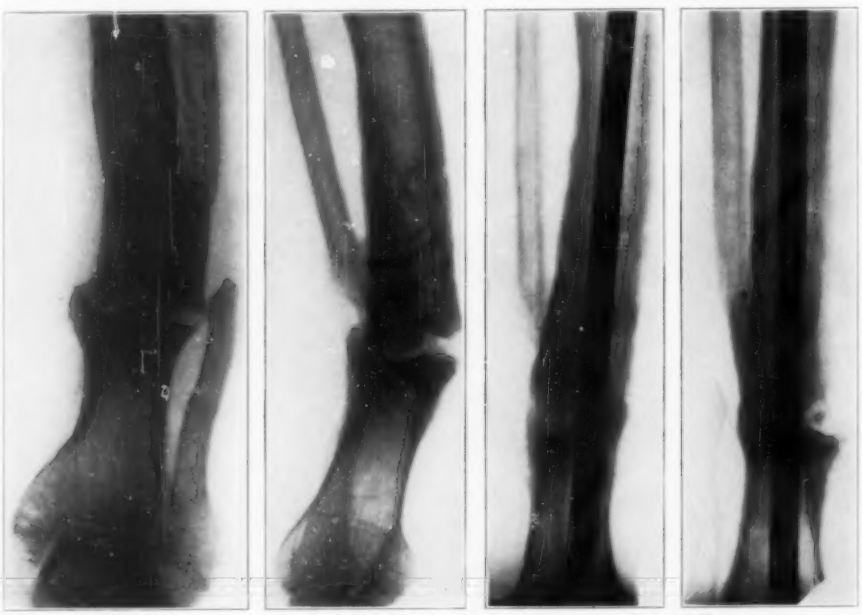

FIG. 11-A FIG. 11-B

Fig. 11-A: These roentgenograms show a pseudarthrosis of the tibia which had been present for six years.

Fig. 11-B: Healing of the pseudarthrosis was obtained by reaming and intramedullary nailing, without exposure of the fracture site.

and, above all, my long clinical experience in numerous cases have shown that these factors have no effect on the bone or on the healing of a fracture or of an osteotomy cut. As shown in Figures 8-A and 8-B, the bone will soon grow thicker and the cortical wall will regain its original width. While endosteal callus will scarcely appear, intramedial callus and particularly periosteal callus will form all the more extensively.

It can be consistently demonstrated that the presence of a metal nail does not cause pseudarthrosis. This fact may be proved in cases in which pseudarthrosis has occurred by merely removing the nail through the entrance canal, reaming out the medullary canal, and inserting a strong nail. The case illustrated in Figures 9-A, 9-B, and 9-C shows that in intramedullary nailing the danger of pseudarthrosis can definitely be avoided. The nail alone, if it is strong enough, will prevent pseudarthrosis. Additional safety measures, such as circumferential wiring or the use of plaster casts, are not only meaningless but even harmful!

Other dangers previously feared have also been eliminated. The threat of infection has been checked by antibiotic drugs. The perfection of reduction instruments makes it possible to perform closed nailing of fresh fractures without exposure of the fracture site, and osteotomy can always be performed in such a manner that the periosteum remains in contact with the bone and the surrounding soft tissues. Another great advantage of nailing is that the normal blood supply of the bone is damaged very little with the result that the chances of infection or sequestration are minimized. We have also learned to avoid the danger of x-ray injury to the assistants. Roentgenograms are made with short exposures and by remote control of the x-ray unit. During the moment of exposure even the anaesthetist may leave the room. An ideal solution to the problem of x-ray control is the electronic fluoroscope. The resulting pictures are so bright that they can be seen without adaptation and their outlines are almost as sharp as those on the film; yet, the radiation energy has been reduced to a small fraction of its former power, which practically eliminates the danger of x-ray injury.

Another benefit of intramedullary nailing is that the danger of fat embolism can be effectively counteracted. During the last ten years I have not observed the slightest indication of its presence. One of the precautions I have taken is that I have not nailed

FIG. 12

Special instruments developed for use in the insertion of the Küntscher nail: a flexible, cannulated reamer on a guide pin and a flexible reamer used with a guide pin (length 500 millimeters).

the fracture until the fifth or sixth day after the injury, thus allowing time for any fat which entered the circulatory system during the trauma to be eliminated. Fat embolism is caused by excessive pressure in the medullary canal, which therefore must be carefully avoided during the nailing. If the entrance canal of the femur is reamed open and the nail slowly hammered in, there will be opportunity and time for the fat to be drained off. Actually, at the beginning of the era of nailing, most deaths were not caused by fat embolism but rather were the result of the shock caused by too extensive and too prolonged manipulation during reduction.

Intramedullary nailing has made successful contributions in a wide field outside the treatment of fractures. Its success in the treatment of pseudarthrosis has been especially impressive and during recent years it has become possible to treat this condition in the majority of instances by closed nailing. The excellent results of Phemister's method show that the removal of connective tissue at the fracture line and resection of the bone ends is completely unnecessary. For best results it will suffice to ream out the medullary canal and to insert a nail of sufficient width. A patient with pseudarthrosis will be particularly impressed by the intramedullary-nailing method because, in contrast to patients with recent injuries, he has usually gone through years of unsuccessful treatment with plaster casts and bone grafts. He now finds that insertion of a nail through a simple stab incision will suffice to immediately restore strength and usability of his extremity and to eventually achieve healing of the bone. Figures 10-A and 10-B show a pseudarthrosis of the forearm which had been present for five years. Figures 11-A and 11-B show a pseudarthrosis of the tibia which had been present for six years and which had been treated several times by the insertion of bone chips. In both cases healing was obtained by the insertion of a nail through a small stab incision one to two centimeters long, without exposure of the fracture site.

Electrical Burns of the Upper Extremities*

BY G. KENNETH LEWIS, M.D., CHICAGO, ILLINOIS

In spite of the many safeguards constantly being developed to minimize the hazards of accidents caused by electrical burns, there is a general lack of knowledge regarding the intricacies and dangers involved in contact with high- or low-tension electric current. The incidence of electrical burns is increasing with our growing use of electricity.

In an attempt to obtain statistics from various sources on the frequency of non-fatal electrical burns, the author found that, in most cases, these data are included in the statistics relative to burns *per se*, and are not classified under initial causes. However, the over-all figures on fatalities from electric shock, the primary cause of death in accidents resulting from contact with electricity, are low compared with those of thermal burns. The National Safety Council of Chicago quoted the latest available figures obtained from the National Office of Vital Statistics. It gave a national total of 965 fatalities from contact with electric current, and 6,083 from fire and explosion of combustible material for the year 1954.

My purpose is to discuss the frequent seriousness of burns and shock from electric current; the type and amount of current; tension; resistance; individual susceptibility; the characteristics, appearances, and degrees of electrical-burn lesions; and treatment, both initial and definitive, with special reference to the upper extremities.

Scientific knowledge of the effect and destructive action of electric current on the human body has developed only within the last century, for it was within this period that man first learned to use electricity. Since that time it has been harnessed for light and power, in high voltage and amperage, and in alternate or direct current.

The medical profession has become aware of the basic differences in the underlying pathology of electrical burns as compared with thermal burns. While it is possible to estimate accurately the extent and depth of thermal burns on the second or third dressing, it is impossible to assay the damage caused by electrical burns for many days, sometimes weeks after the accident. In the latter injuries, intense heat has been introduced into the body, causing dangers of vascular trauma and progressive lesions. In the early phase of any type of electrical injury, any immediate determinations or predictions of the degree of damage sustained can, and should, be only a nebulous conjecture.

The generation of heat resulting from electric current traveling through the human body is similar to that of heat resulting from current passing through a conductor. This heat causes destruction of the cells, stimulation of strong muscle contracture, inhibition of functions of vital organs in the path of the current, full-thickness skin loss, volatilization, necrosis and, in some cases, actual elimination of bone. It is well known that the melting point of iron is 1,510 to 1,570 degrees centigrade, and that of calcium, 700 to 900 degrees centigrade. Electric arc welding temperatures of 3,250 to 3,300 degrees centigrade are not uncommon. Baldridge has pointed out that in electric arc burns the tissues are heated by a current of 2,500 to 3,000 degrees centigrade, and that tissues including bone are melted and volatilized.

An electrical injury will occur when some part of the body is interposed between two electrodes to complete an electric circuit or arc. For example, a live wire may be touched with impunity so long as such contact does not complete a circuit and result in a flow of electric current through the tissues. When contact, direct or indirect, results in such a flow from one electrode to another, or from an electrode to the earth, the symptoms may be immediate, secondary, or delayed. The harmful effects and the extent of the

* Read at the Annual Meeting of the American Society for Surgery of the Hand, Chicago, Illinois, January 25, 1957.

damage upon an organism depend upon several factors: type and amount of current (voltage and amperage), resistance (ohms), path of the current, duration of contact, and individual susceptibility.

TYPE AND AMOUNT OF CURRENT

Voltage

Electric current of 1,000 volts or less is considered low tension; above 1,000 volts, high tension. Anything above sixty-five volts or thereabouts, may be considered dangerous, especially if the person is well grounded. In fact, Jellinek found currents as low as twenty-five volts dangerous when the body was wet and well grounded [15]. Williams stated that 110 volts may prove fatal if contact is made on moist skin, and current passes through the heart in sufficient quantity to throw the ventricles into fibrillation [31].

Shock received in electrical accidents depends more upon the conditions of contact than upon the nature of the current with which it is made. It has been demonstrated that brief contact with a 1,000-volt high-tension current with a dry hand or finger may be less dangerous than 110 volts grasped with a wet hand with the body wet and well grounded.

Alternating current, however, is about three times more dangerous than direct current of the same voltage and amperage. The number of cycles is important. When the cycles range from about thirty to 150 there is more danger, for as the number of cycles increases, the danger diminishes. This is explained by the fact that muscles and nerves are insensitive to very high frequencies.

High-tension wires usually carry alternating current of high voltage and amperage. Frequently, it is necessary to forcibly detach the victim from contact with such a wire. If this is necessary, the rescuer must first take precautions for his own safety by using a non-conductor such as a piece of wood or rubber to knock the wire from the victim's grasp or contact. The following case is an example.

Case 1. L. M., a man, fifty-six years old, was helping to move a house, and was attempting to lift some high-tension wires of 2,300 volts. He apparently became grounded and was severely shocked and burned. The driver of the truck which was pulling the house saw what had occurred, increased the power to the tractor and pulled the victim loose from the wires. He was taken to the hospital for emergency treatment.

The patient was then referred to another hospital for specialized care of extensive electrical burns of both hands. The left hand was extensively gangrenous and demarcated five centimeters above the left wrist. All tissues through practically the full thickness of the wrist were soft, necrotic, and tender. The right hand and wrist had a large burn, and the ventral surface of the wrist had extensive necrosis of the tissues, extending down to the pronator quadratus. There was a burn on the dorsal surface of the wrist with moderate necrosis. The palmar tendons were devitalized and the fourth finger of the right hand was beginning to demarcate near its base. The left hand was amputated at the middle of the forearm, and pathological specimens revealed gangrene of the left hand and fourth finger of the right hand.

The following was the pathological description of the left hand. The hand measured twenty-two centimeters long and was black in color. There was a large ulceration of the palm of the hand measuring eight by six centimeters and a large ulceration of the wrist measuring eight by five centimeters. The hand was amputated twelve centimeters above the wrist. The skin was completely necrotic and on section there was a foul odor to the tissues. One finger of the right hand was covered with necrotic emphysema and was amputated at the metacarpophalangeal joint. Skin over the palmar surface of this finger was absent, the tendons were necrotic and soft. Numerous pieces of necrotic tendon with the specimens varied from one to five centimeters in length.

A large area of about five to seven centimeters, behind the lobule of the right ear, was granulating. The right hand was granulating on the palm. On the ventral surface of the right wrist, there was a granulating area twelve by eighteen centimeters, and on the dorsal surface of the right hand, there was an open area of about 2.5 centimeters with necrosis. Roentgenographic findings were non-revealing.

Amperage

Amperage is the true measure of the intensity of electric current, and equals the tension divided by the resistance of the conductor. In electrical shock the conductor is the human body. After an accident only the voltage may be determined. The amount of

current or amperage cannot be accurately estimated because, as will be discussed later, the ability of individuals to sustain shock, the variable resistance offered by different body tissues, and the conditions of electrical contact, differ widely.

RESISTANCE OF THE BODY TO THE PASSAGE OF ELECTRIC CURRENT

Resistance of the human body varies according to the prevailing conditions. For example, if the body is dry the resistance can be as high as 5,000 ohms. North noted that this may be reduced to 300 ohms by applying a saline solution to an electrode.

On entering and leaving the body the electric current meets the resistance of the skin. Skin resistance, although variable, is high, and the current when penetrating the integument produces a much greater necrosis in the deeper tissues than on the surface. Several factors influence the variation of skin resistance, such as dryness, cleanliness, thickness, humidity, and vascularity; the size, shape, and nature of the electrodes; and the area and firmness of contact.

Resistance of the skin is raised by its thickness, and in the case of hands, resistance

FIG. 1

Bone necrosis shown. Lesion resulting from an electric current passed through the skull.

of the palmar surface is greater than that of the dorsal. Chapuis stated that resistance of the skin is about 40,000 ohms per square centimeter. Critchley[5] pointed out that perspiration lowers the resistance twelve times and that in water skin resistance drops twenty-five times. When skin is burned its resistance is greatly increased; this may break the current. If carbonization takes place resistance of the skin is reduced.

Bone is the only tissue with a greater resistance than skin. Nevertheless, bone lesions are frequent in electrical accidents, especially when electric current enters the body through the skull. The resistance of bone, such as that of a large surface like the skull with its diploe and blood vessels, is less than that of the layer of soft tissue which covers it. Therefore, the current will pass through the bone (Fig. 1).

Mason and Lester expressed the opinion that necrosis of bone is caused by loss of periosteum. Quenu, however, maintained that bone may live without periosteum and that the necrosis is a direct result of the electric current. The sequestrum may involve particular parts of the entire bone. For this reason, determination of the extent of bone

FIG. 2-A

FIG. 2-B

Bone destruction from electric current: Fig. 2-A shows bone destruction; Fig. 2-B shows roentgenograms made after sequestrum was removed.

FIG. 3

FIG. 4

Fig. 3: Burn produced on the back from a current passing from one extremity to another producing lesions in and near the lower middle thoracic spine.

Fig. 4: Full-thickness, closely circumscribed burns of fingers and palm due to gripping an electrical element. This wound was allowed to granulate, then repaired with a thick free split skin graft.

damage immediately after an electrical accident, is only presumptive (Figs. 2-A and 2-B).

PATH OF THE CURRENT

Lesions produced by electrical accidents are largely dependent upon the path of the current, which is of more significance than its intensity. It is the consensus that currents traversing the left side of the chest or brain are more dangerous, because of their damaging

effect upon the heart, than those passing through the right side of the body. On the other hand, current passing in one extremity and out through another, is seldom fatal. However, while it is important whether vital organs such as the brain or the medulla oblongata are traversed by the current, the amount of electricity to which they are exposed must be considered.

In passing through the skin, electric current chooses the path of least resistance. According to Harrison and Arden, it is conducted through the tissue fluids by the perivascular spaces and through the blood stream, leading to degeneration of the vessel walls. McLaughlin and Coe stated that the vascular channels and cerebrospinal fluid are good conductors of electric current. Finton believed that blood vessels are the best conductors.

Jaffe found that electric current spreads radially from the point of entrance, and is collected again at the point at which it leaves the body [12]. Therefore, the greatest density of current is to be found at the sites of entrance and exit. MacFarlan found that a path of current from one upper extremity to another is prone to produce lesions in the lower and middle cervical cord (Fig. 3). Panse suggested that a foot-to-foot, or leg-to-leg circuit affects degeneration in the lumbar and sacral segments, with late atrophies, paraesthesia, and anaesthesia.

DURATION OF CONTACT

Danger in electrical accidents increases in direct proportion to the duration of the passage of the current, regardless of the type and amount, the resistance, or nature of the contact. Strong tetanic contractions of the entire musculature are produced as the electric current traverses the body. Those of us who have observed electrical accidents, have seen victims in a state of extreme opisthotonos, with muscles torn, joints dislocated, and bones fractured. These strong muscle contractions may fling the body away from the contact and break the current, or the individual may be fixed to the conductor until the current is broken. Dale likened this to the case of a child gripping a cold electric element while a playmate switches on the current. This, he stated, is a very common accident among children, and usually results in full-thickness, closely circumscribed burns on fingers and palms. In such accidents some current passes through the child (Fig. 4).

If the accident occurs with alternating current, the hand or hands cannot be withdrawn because of a tetanizing effect.

Williams in a study of electrically burned hands in children, found a high incidence of contracture deformities after full-thickness burns [30]. Frommolt described the fixation of a hand, through which a current had passed, as claw-like for hours after the accident. This demonstrates the tetanic contractions which sometimes outlast the passage of current. Frommolt described the muscles in such patients as firm, dry, reddish, and friable.

Schmidt studied the microscopic picture of similar cases, and found a displacement of the contractile substance. Instead of the usual fine cross striation, he noted coarse, hyaline, transverse bands. The fibrils passed through these bands which were composed of the compressed anisotropic discs of the muscle fibers. These were the sites of the most extreme and irreversible contractions. Therefore, it is obvious that electrical burns of the upper extremities, complicated by contracture, can be severe and result in crippling deformity (Fig. 5).

DESTRUCTIVE EFFECTS OF ELECTRICAL SHOCK UPON THE CENTRAL NERVOUS SYSTEM AND THE HEART

The usual symptoms of electrical shock are headache, vertigo, nervousness, insomnia, defective memory, psychoneurotic syndromes, states of mental aberration with delirium, and sometimes a complete personality change. These frequently develop some months after an electrical accident.

Critchley described the morbid changes which may occur during electrical shock

FIG. 5

There is a marked thickening of the squamous epithelium with hyperkeratosis and acanthosis. The basal cell layer is intact. The granular layer is thickened. The epithelium thins out gradually and disappears. Beneath the epithelium, there is coagulation necrosis of the connective tissue. The remaining connective tissue shows hyperaemia and round-cell infiltration.

as severe cerebral oedema associated with high intracranial tension. He described the principal lesions as: petechial hemorrhages throughout the central nervous system especially in the region of the fourth ventricle and medulla; chromatolysis of the neurons throughout the central nervous system and, in the peripheral nerves, fragmentation and twisting of the axons, breaking down of the sheath of Schwann with fusion of its constituent nuclei, and endothelial infiltration of the epineurium. He compared an electrical shock to a blow hard enough to cause a cerebral concussion [6].

Drinker stated that the victim of electrical shock may be found in one of several conditions: (1) respiration may have ceased but the heart and circulation remain normal (due to tonic spasm of the respiratory muscles); (2) respiration and circulation may have ceased simultaneously after the ventricles of the heart have gone into fibrillation; and (3) respiration may be present but the heart stopped as in ventricular fibrillation. Jaffe stated that currents of low tension kill by producing ventricular fibrillation; high-tension currents kill by causing paralysis of the respiratory center; and medium tension (400 to 600 volts) has perhaps an injurious effect upon both circulatory and respiratory centers.

Although some difference of opinion exists as to whether death in electrical shock

FIG. 6

FIG. 7

Fig. 6: Apparently healthy tissue surrounding an electrical burn is shown.
Fig. 7: Vulnerability of blood vessels and extensive damage produced by late thrombosis resulted in gangrene of both hands. Treatment consisted in close observation until demarcation of tissues occurred, then amputation.

is caused by cardiac damage or respiratory paralysis from action on the medulla, there is a growing belief that most electrical fatalities are caused by direct action of the electric current on the heart, causing ventricular fibrillation. Once established, this is usually permanent, although Kerr and Bender reported a case in which recovery occurred spontaneously. Koeppen demonstrated from animal experiments that cardiac damage is the principal cause of death in these accidents. Victims of electrical accidents may be found in shock and severely burned or there may be no burns at all. Both may occur simultaneously, as illustrated in Case 2.

CHARACTERISTICS AND APPEARANCE OF ELECTRICAL BURN LESIONS

One primary characteristic of electrical burns, as stated previously, is their tendency to progress beyond the visible changes noted immediately after an accident. Appearance, markings, progression, and other characteristics of electrical burns in many ways are different from thermal injuries. Dale stated that "The further science probes into the nature of the universe the more clear does it become that electrical phenomena and electrical forces are manifestations of the ultimate structure of matter. It might therefore be expected that lesions in living tissue caused by the action of electrical forces should have unique characteristics."

Apparently healthy tissue surrounding a wound resulting from an electrical burn may become necrotic (Fig. 6). At times an entire extremity is involved, sometimes at a distance from the site of entry of the current. Jellinek noted that the walls of the vessels through which the current traverses are friable and brittle, the endothelium is changed, and parietal thrombi are attached to the intima [16]. The great vulnerability of the vessels, and the extensive damage to the media and intima, account for the severe meningeal damage, hemorrhages, and late thrombosis commonly encountered in patients with electrical burns. This is also an occasional cause of massive gangrene of an extremity (Fig. 7). Likewise, it explains the great difficulty often experienced in ligation of the arteries near the wound, as illustrated in a previous article on electrical burns by the present author [20]. The most marked change noted has been extensive necrosis of the media, and it has been observed that vessels become brittle to the point that ligation is impossible.

Electrical burns may be divided into two types:

1. *Contact Burns*

These vary from pin-point size to large surface areas. Wounds from electric sparking

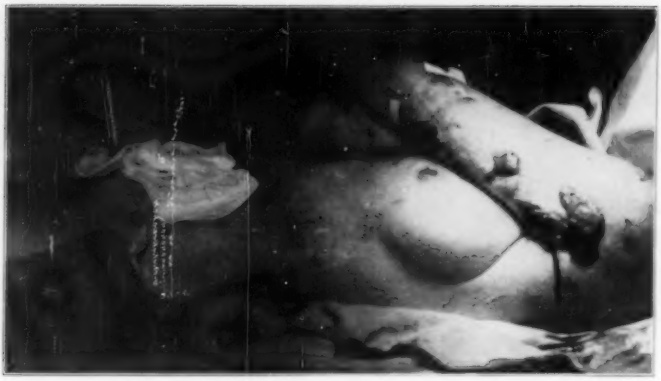

FIG. 8

Contact burns varying from pin-point size to large surface areas are shown.

and contact with high-tension current (Fig. 8) differ from those caused by electric heat and chemical burns. Their principal characteristics are absence of pain, maintenance of their original appearance for days or weeks, and a marked tendency to heal after a period of latency of a few days or even weeks. In these burns, portions of the soft tissues as well as bone in the region of the wound, may separate spontaneously without causing any noticeable discomfort or suppuration.

2. *Arc Burns*

As stated previously, in this type of burn extreme temperatures of 2,500 to 3,000 degrees centigrade are developed. This is the most serious type and in these burns there is frequently a final slough in excess of the original burn. Because of the extreme heat generated, there are often accompanying thermal burns of varying degree.

The effect of the current upon the skin has been described by Jaffe:

1. In passing through skin the electric energy is transformed into heat, altering the structures along the way of the current. The result is the so-called current marking which is, to a certain extent, specific and of diagnostic value.

2. Free discharge causes formation of electrical sparks which lead to formation of third-degree burns. Burns from high-tension electricity may entirely obscure the typical markings usually seen after low-tension accidents.

FIG. 9

FIG. 10

Fig. 9: Spontaneous separation of soft tissues and bone. The tissues were covered with a pedunculated abdominal flap, following débridement of known devitalized tissue.

Fig. 10: A hole in the skin, muscle, and bone produced by steam generated in the deep tissues. The steam exploded to the surface under great pressure. Desquamation usually occurs in the devitalized tissue. Healing occurs only after the slough has been thrown off.

In arc burns, electrical markings are seen at the sites of entrance and exit of the current. In the macroscopic appearance of a typical current mark, the shape is round, oval, oblong, linear, or rosette-like; the size varies from a few millimeters to several centimeters, and the surface shows a negative of the electrode, as in Figure 4. Besson characterized the burns caused by high-tension electric current by their combination of current markings which form a homogeneous block uniformly mortified in all parts. They are greyish in color, with elevated edges, and appear to be located in the intact skin like a seal. In the center, a deep groove extends down to the underlying structures, into the muscles, and sometimes even into the bone. The walls of the groove are irregular, black, and at times covered with deep red islands.

As in the typical current markings, pain and suppurative reaction are rare. Demarcation of all the necrotic tissue may lead to severe functional disturbances. Jellinek described a rare type of current mark resembling a bullet wound; a round hole penetrating the skin, musculature, and bone. He explained the lesion as the result of the sudden formation of steam in the tissues which finds its way out under extreme pressure (Fig. 10).

FIG. 11

Deep and extensive burn with the entire back and front of the hand resurfaced with an abdominal flap.

Lightning Burns

Burns resulting from lightning manifest a diversity of effects. The very sudden discharge of current produces a flash, and the resulting lesions may take the form of superficial or deep charring of the skin, extensive full-thickness skin loss, and frequently punctate, usually multiple, areas of full-thickness skin loss.

Paraesthesia and temporary loss of power in the limbs are often encountered, caused by the passage of current along the peripheral nerves. Burns in these accidents may be deep if the body of the individual is wet when struck by lightning. If the victim is dry and well insulated from ground contact, there may be no skin burns, but the possibility exists of tissues being torn due to heat and steam generated in the tissues. The clothing is frequently stripped off, and any metallic object in contact with the body may become heated and cause secondary thermal burns.

INDIVIDUAL SUSCEPTIBILITY TO ELECTRIC CURRENT SHOCK

Resistance of the body at the time of an electrical accident and the ability of different individuals to sustain electrical shock vary. Certain people are extremely sensitive to shock while others sustain it with equanimity. It has been demonstrated that it is not a question of physical build. It does seem apparent, however, that elderly people, persons with arteriosclerosis, alcoholics, individuals with disturbed function of the thyroid gland, and those with chronically greasy skin, are all more susceptible to shock. It has also been observed, that some persons with heart disease can withstand as much shock as those with a normal heart. Individual resistance also appears to vary somewhat according to

sex, nationality, and temperament, and vary in the same person at different times. A significant point, nevertheless, is that individual susceptibility to electricity is a factor, and that current causing extreme injury or fatality in one instance, may have little or no effect upon another individual.

This would seem to explain the phenomenon frequently observed in electrical injuries, that is, that when individual resistance at the point of contact is high, burns may be severe and the systemic damage slight. Conversely, when there is low resistance, burns will often be slight and the systemic effects severe. According to Jaffe, Willis, and Backem, full consciousness is maintained by some victims of an electrical accident, while others lose consciousness completely, and become comatose immediately when the circuit is broken. Shock, in itself, often accounts for death in a victim of an electrical accident who is only slightly burned. For this reason, a history of electrical shock and unconsciousness, may have marked clinical significance.

Case 2. B. S., a woman, forty-six years old, was walking below an electric power line on which repairmen were working. The power line fell, striking several parts of her body, knocking her to the ground. She became unconscious and breathing stopped completely. She was given emergency treatment including artificial respiration, by a doctor passing by the scene of the accident. It was estimated that in approximately twenty minutes of the accident she was admitted to the hospital, where her condition was described as resembling hysteria. Restraint by force was necessary, and the patient was given intravenous pentothal sodium.

Physical examination revealed a markedly disoriented, excited individual, in shock, with skin of good color. There were multiple burns over the head, left arm, hands, trunk, legs, and perineum. The extent of the burns could not be immediately determined. Pulse was 120, slightly irregular, and blood pressure was 140 systolic and 84 diastolic.

Several days later the objective findings were a transverse third-degree burn of left frontal area, approximately five by ten centimeters in size, down to, and including the outer table of bone. There were two irregular lacerations of the scalp about seven and fifteen centimeters long, one in each parietal occipital region. Third-degree burns involved the entire lateral aspect of the left arm, left scapular region, lateral aspect of the left thigh, and an area about seven by eighteen centimeters on the lateral aspect of the left leg. Similar burns approximately 2.5 by five centimeters in diameter were present over the lateral and dorsal aspect of both feet; one was over the right heel. Small first- and second-degree burns were scattered over the right thigh, right knee, and right heel, and small first-, second-, and third-degree burns were scattered over the right anterior lower portion of the abdomen. Over each antecubital space there were third-degree burns approximately five centimeters in diameter and a minor flesh burn over the perineum. An extensive third-degree burn over the dorsal aspect of the left wrist had cut across the extensor tendons of the wrist and index fingers, baring the distal fourth of the ulna and proximal portion of the wrist joint. Apparently the tendons on the left thumb were intact. The blood supply to the left hand was also intact, but there was sensory impairment. There was loss of sensation of the index and middle fingers of the left hand, and partial loss of sensation in the ulnar distribution of the ring and little fingers. First- and second-degree burns involved the ulnar and dorsal aspect of the left hand, with no loss of deep structures in that region. Small, irregular, third-degree burns were present on the lower aspect of each wrist. Severe third-degree burns involved the entire palmar aspect of the fingers of the right hand, with total loss of tissue of the palmar aspect of the index finger, almost total loss of the third finger, loss of soft tissue over the middle phalanges of the proximal and distal segments which were bare; and the proximal end of the phalangeal joints were frail. The phalanges of the other fingers of the right hand were still covered, and skin was of good color and normal texture.

Roentgenograms made at this time were essentially normal. Those made seventy days after the accident revealed the following: on the lateral view of the skull showing the frontal sinus and head, there was a sequestrum of bone, appearing to be separated from the inner table and ready for removal. There was considerable rarefaction of the left hand; there was ankylosis of the second and terminal phalanges of the thumb and loss of the metacarpal bone of the index finger; and there was considerable rarefaction of the carpals from disuse.

On the twenty-first day after the injury, débridement of the right hand, split-thickness skin graft over the left arm, and amputation of the right index finger were performed. Eight days later, the left hand was attached to an abdominal flap, and a split-thickness skin graft was applied to the right leg. Three weeks later, the abdominal flap was detached, with closure of the abdominal defect and application of the flap to the left wrist and hand. A secondary closure of the granulating area over the left buttock and thigh was performed ten days later, and approximately ten days after this, a skin graft was applied to the right thigh, abdomen, left arm, and left shoulder.

About five months after the injury, tendons were transplanted to the thumb as a definitive measure. Fatty subcutaneous tissue overlying the dorsum of the right thumb was removed. An arthrodesis of the proximal phalangeal joint of the middle finger of the right hand was performed, and the finger was fixed

in slight hyperextension. This finger was brought into slight flexion at the distal joint to obtain apposition with the thumb. A short time later, a tendon transfer of extensor carpi radialis longus to extensor pollicis longus was performed to give extension to the thumb. More of the excess subcutaneous tissue from the flap of the dorsum of the hand was removed as a final operative procedure.

TREATMENT

The most important emergency medical treatment in electrical injuries consists in artificial respiration, cardiac massage if applied within five minutes of the accident, and cardiac stimulants. Baldridge has also suggested using intra-arterial or intracardiac injections of potassium and calcium salts. In some instances prophylactic tetanus and gas antitoxin may be indicated.

In the treatment of injuries, the literature still reveals some divergence of opinion regarding the timing for definitive care of electrical burns. The author is of the opinion that a conservative therapeutic approach is important. As previously pointed out, the examinations do not permit an accurate estimate of the extent of the injury even after days or even weeks, because damage to soft tissues and bone is progressive. Therefore, an injury, appearing relatively simple, may ultimately become catastrophic. Furthermore, the difference in the characteristics, pathogenesis, and pathology of electrical burns compared with thermal injuries, makes a period of delay possible before attempting débridement and definitive care of electrical burn lesions without danger to the patient.

According to Baldridge there are five reasons for this:

1. In the sealing off of avenues of bacterial invasion in current burns, the hazard of infection is not serious;
2. With the coagulation of skin, lymph, and blood vessels, plasma loss and electrolyte disturbance are minimized;
3. Pain in the interim is not severe, because of sensory nerve destruction;
4. There is a minimum of toxic absorption;
5. Although albuminuria and hemoglobinuria may appear for a few days, renal failure has not been reported.

The author concurs with those who adopt a hands-off policy whenever feasible in electrical burn patients and who feel it is wise to defer primary repair or an amputation until the progression of tissue damage, bone sequestration, demarcation of dead tissue, deep necrosis, separation of sloughs, and the tendency toward progressive thrombosis has been stabilized or has ceased (Fig. 9). This is significantly true in the case of the upper extremities, where a finger or even an arm may appear viable soon after injury, but subsequently become cyanosed and ischaemic in a few days. Normal appearing granulations often persistently resist skin grafts until the latent period has passed. Therefore, purposeful but assiduous delay may prevent a serious difficulty such as uncontrollable hemorrhage during premature surgery and may eventually preserve all possible function to a hand or an extremity. It may also avoid the necessity of possible multiple operations later for restoration of function and appearance.

Nevertheless, as quickly as the final extent of destruction is accurately ascertained, it is important that definitive repair be instituted and accomplished. Understandably, the longer the burned area is left unnecessarily without cover, the more likely it is to become infected. This would increase tissue destruction, and work against the survival of grafts when applied. It is of particular importance that bones and tendons not be exposed and left without cover for an unduly long period. Here infection, non-union, and other, sometimes irreparable sequelae, may result. Connelly stated that if bone becomes exposed after thermal injury, it is usually because of separation of third-degree slough, where overlying skin is thin over bony prominences, especially over interphalangeal joints of the hands. He pointed out that bone destruction here, however, is not deep and not common, and that early coverage compatible with the patient's condition should be

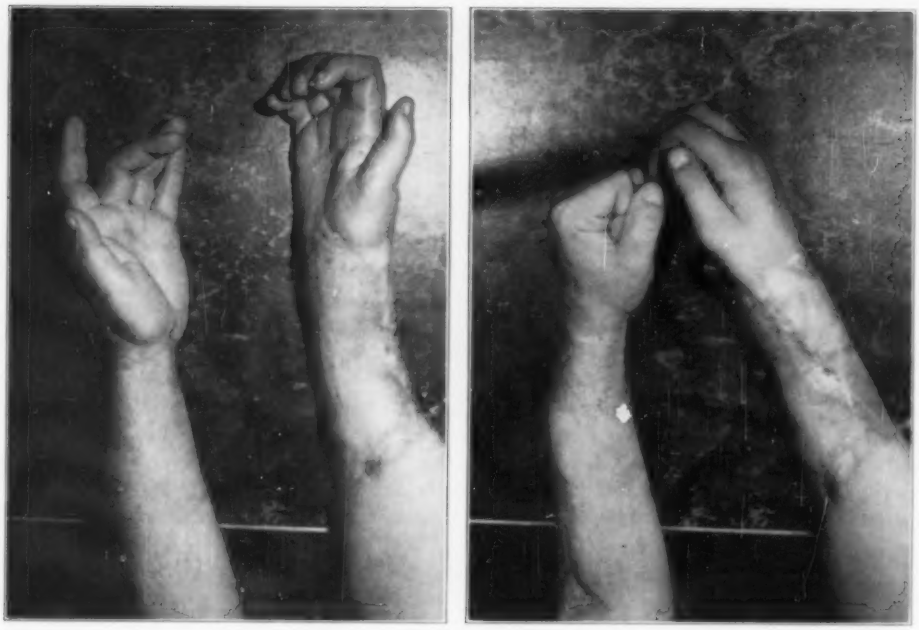

FIG. 12

Tissue replaced by abdominal flaps.

performed. Electrical burns with widespread tissue destruction and those accompanied by fractured bones present a different problem; here one must wait for some degree of demarcation, and flaps will often be required to handle the defects.

In the definitive care of the hand and upper extremity burned by contact with electric current, the entire necrotic area is ultimately excised and then covered with a graft of indicated tissues, such as split-thickness or full-thickness grafts or pedunculated flaps. Skin flaps are used when tendons are exposed or joints are open. It is desirable to use local flaps when feasible. However, in deep and extensive burns, the entire back or front of a hand may have to be resurfaced with an abdominal flap (Fig. 9).

There are numerous accepted procedures for reconstructive surgery of the upper extremity, including methods for skin, tissue, and bone replacement. On the subject of bone replacement, the author reported the value of cancellous bone and his own satisfactory results. It was found to be readily molded with a certainty of growth, without the disadvantage of introducing a foreign material into the tissues. The ultimate anatomical, physiological, and cosmetic results were good [19].

Regarding the specific repair of the traumatized hand, the author described his successful use of contiguous and single pedicle flaps. These flaps were found particularly adaptable to the early repair of the hand because of rapid replacement of lost tissue, good return of function, sensation, strength, and an improved appearance (Fig. 12), as well as a bed for the definitive tendon transplantation when necessary [21].

Detailed description of the foregoing procedures employed by the author would be too extensive for the scope of this paper. However, those interested in these particular methods, are referred to the specific reports.

Complicated, meticulous reconstructive operations are often required in repair of electrical injuries, and tissue replacement often presents a difficult challenge to the surgeon to obtain healing and return of function and appearance. In this regard, Williams quoted

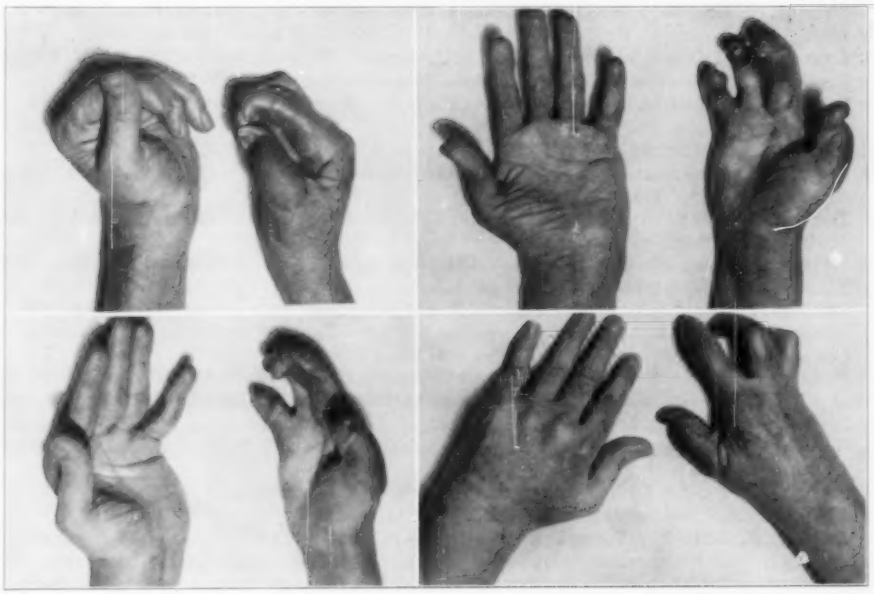

FIG. 13

Hands are shown following arthrodesis of the middle finger of the right hand, and tendon transfer of the extensor carpi radialis longus to extensor pollicis longus to give extension to thumb, permitting approximation of thumb and tip of middle finger.

McIndoe who stated, "A burned hand may be a lesion of no great severity and without subsequent disability, or it may result in the most crippling deformity comparable only to loss of vision" [30].

In the after-care of upper extremities, one should be aware of the large amount of fibrous tissue produced by electrical burns, and the rehabilitation frequently necessary. In these patients, when extensive tissue destruction exists, much tissue replacement and sometimes radical reconstructive surgery is mandatory in order to prevent disability.

COMMENT

In the therapy of electrical injuries, there is, as previously pointed out, a difference of opinion between those advocating early definitive care and those who recommend a conservative approach. The author favors a conservative approach whenever possible, based upon the insidious progressive nature of electrical burn lesions.

Nevertheless, in the final analysis, the decision as to timing for débridement and definitive care, must be an individual judgment of the surgeon. This must be influenced largely by tissue destruction and condition of the patient. Likewise, the choice of operative procedures or specific techniques must be an individual one.

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Osteotomy-Bunionectomy for Hallux Valgus*

BY C. LESLIE MITCHELL, M.D., JOSEPH L. FLEMING, M.D., RICHARD ALLEN, M.D., CHRISTOPHER GLENNEY, M.D., AND GLENN A. SANFORD, M.D., DETROIT, MICHIGAN

From the Division of Orthopaedic Surgery, Henry Ford Hospital, Detroit

A preliminary report of an original operation for hallux valgus was published in 1945 [6]. The paper emphasized the role played by metatarus primus varus in the etiology of hallux valgus. The operation consisted in a lateral displacement-angulation osteotomy of the first metatarsal neck to correct metatarsus primus varus and a medial capsulorrhaphy to correct the hallux valgus.

The operation has continued to give satisfaction to most patients over the more than twenty years since it was developed. An end-result study was carried out in 1955 in which questionnaires were sent to all patients who had been operated upon. One hundred and twenty patients who had had 204 operations responded. Of these, fifty-nine patients, who had had 100 operations, agreed to come to the hospital to be examined by the authors in the fall of 1955. This paper is based on the study of those 100 operations. No other methods of selection were used.

The follow-up study included a detailed review of the questionnaire, examination of the feet, roentgenograms and photographs. The data contained in this paper were gathered from only the fifty-nine patients who could be studied in detail and in person. We have verified the opinion of many authors that use of the questionnaire alone is an inadequate method of follow-up study.

Although, in general, the patients judged their results on a reasonable basis, such as relief of pain and correction of deformity and ability to wear normal shoes, in some cases a result reported in the questionnaire as completely satisfactory was judged less than that by the surgeon. Again, some patients expressed dissatisfaction in the face of an excellent result because of bunionettes, hammer toes, unrelieved second metatarsal pain, and other symptoms. The importance of a personal interview and examination in this type of follow-up study cannot be overemphasized if this method of correction is to be critically compared with other surgical approaches to hallux valgus.

Over 400 of these osteotomies have been done since 1935, and we feel that the results of this study warrant the continued use of this operation. However, as will be shown, patients must be carefully selected and the operation done precisely to obtain good functional and cosmetic results.

This material, as well as a study of the history of bunion surgery and of theories of etiology, carried out as part of an exhibit at the Annual Meeting of the American Academy of Orthopaedic Surgeons in 1956, will be presented in a separate report.

ETIOLOGY OF HALLUX VALGUS

The senior author has long believed that metatarsus primus varus is the primary deformity and that it is congenital. The hallux is gradually pushed laterally first by the shoe and subsequently maintained in a valgus position by the bowstring effect of the long extensor tendon. In time a contracture of the lateral capsule and adductor hallucis develops so that full passive correction is no longer possible. Finally, a painful bursa develops over the prominent medial part of the metatarsal head and varying degrees of exostosis formation may develop. The first metatarsal fails to assume its proper role in weight-bearing; this is partly due to the inefficient push-off of the laterally displaced hallux. In many patients second metatarsalgia develops as a result of this failure. Other

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 29, 1957.

factors in the development of metatarsalgia are the laterally displaced sesamoids and the effort on the part of the patient not to bear heavily on the painful great toe and first metatarsal.

The role of metatarsus primus varus in the etiology of hallux valgus has been emphasized for many years by various observers. Recently Bonney and Macnab, Hardy and Clapham, and Durman have given additional evidence of the basic role of this deformity. The normal angle between the first and second metatarsals is under 10 degrees. Most patients in our series with significant hallux valgus had an intermetatarsal angle of from 10 to 22 degrees. Figures 1-A and 1-B demonstrate the method of measurement in the preoperative and postoperative roentgenograms.

Measurement of the Intermetatarsal Angle

Points are marked at the center of the articular surface of the metatarsal head and at the center of the proximal articulation. The points are connected by a line which is projected proximally until it bisects a line drawn down the axis of the second metatarsal. Note that the center of the articular surface of the metatarsal head (excluding the exotosis) is chosen rather than the long axis of the shaft of the first metatarsal, in the event the lines do not coincide. This provides a method for measuring the postoperative angle. It is important that roentgenograms be made of the patient's foot while he is bearing weight since there is an appreciable increase of the angle compared with that seen in routine films.

RATIONALE OF THE DISTAL OSTEOTOMY

Regardless of the pathomechanics of hallux valgus, it is evident that to correct only the toe deformity without simultaneous correction of the metatarsus primus varus, when present to an abnormal extent (over 10 degrees), will lead to recurrent deformity

FIG. 1-A

Preoperative roentgenogram reveals metatarsus primus varus of 18 degrees on the right foot and 13 degrees on the left. The lines are drawn from the center of articular surface of the metatarsal heads to the center of articular surface of the metatarsal base. The normal intermetatarsal angle is less than 10 degrees.

in many patients. This is because the hallux cannot articulate normally with a metatarsal that is pointing medially unless it is in varus deformity, a position that the modern shoe will not tolerate. From our study, it is clear that there is a high correlation between the correction of the metatarsus primus varus and the clinical result (Chart VII). This lends direct evidence to the importance of the correction of the intermetatarsal angle, and indirect evidence to the role of metatarsus primus varus in the etiology of hallux valgus. (Indirect because theoretically the hallux valgus could cause the metatarsus primus varus.)

Durman said that the underlying cause of the metatarsus primus varus is medial obliquity of the metatarsocuneiform joint and he based his operation on correction and fusion of this joint. Other authors previously held a similar view and devised similar operations[1, 2]. We agree that the increased angulation of the first metatarsal probably develops at the metatarsocuneiform joint rather than more proximally.

In theory it is better to correct the metatarsus primus varus at or close to its point of origin. However, we have found the distal osteotomy a simple and sure method of correcting the metatarsus primus varus where it is most effective — at the metatarsophalangeal joint. Also the slight shortening that occurs as a result of the osteotomy allows relaxation of the lateral capsule and adductor hallucis muscle so that lateral release of the metatarsophalangeal joint is usually not required. Following the osteotomy the displacement of the hallux will reduce without tension (which predisposes to stiffness and recurrence) and stay reduced if an adequate medial capsulorrhaphy is done. The effect of the metatarsal shortening will be discussed later.

If the correction is done proximally by open wedge osteotomy or fusion, an extensive lateral release or a distal medial closing wedge osteotomy[3, 8] is still necessary to

FIG. 1-B

Postoperative roentgenograms of the right foot showing correction of the intermetatarsal angle from 18 degrees to 5 degrees. A plantar angulation of the osteotomy site of 30 degrees is marked by the dotted line in the oblique view.

correct the hallux valgus due to the lateral contracture of the metatarsophalangeal joint. This latter procedure straightens the toe but of course leaves the proximal phalanx in its preoperative position of lateral subluxation.

Finally, by a combination of exostosectomy and lateral shift of the metatarsal head, a significant narrowing of the foot is obtained. This narrowing will often allow the patient to wear high-heeled shoes. The authors have no objection to this type of shoe, feeling that if the varus deformity of the first metatarsal is fully corrected, the danger of recurrence of hallux valgus is small. These two advantages make the operation desirable from the standpoint of women. A good result from this operation will be superior cosmetically and functionally to a good result from a Keller operation or other excision arthoplasties.

OPERATIVE TECHNIQUE

This procedure may be described as osteotomy of the distal portion of the first metatarsal, lateral displacement and angulation of the head of the metatarsal, with exostosectomy and medial capsulorrhaphy. As far as can be determined by an extensive search of the world literature, it was first described by the senior author and associates in 1945. The only procedure similar in principle was described by Mygind in 1952.

A dorsal medial incision is made on the foot, curving above the bursa and callous (Fig. 2-A). The insert shows the lateral subluxation of the hallux.

A Y-shaped incision (Fig. 2-B) is made through the medial capsule and the periosteum of the first metatarsal. The arms of the Y should meet one-quarter of an inch proximal to the metatarsophalangeal joint. If the arms of the Y extend too far proximally, insufficient tissue is left to obtain secure medial capsulorrhaphy.

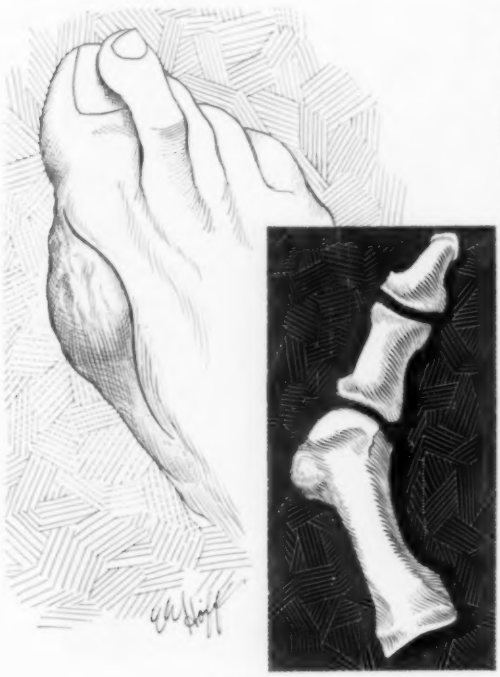


FIG. 2-A

FIG. 2-B

Fig. 2-A: Drawing shows the curvilinear anteromedial incision.
Fig. 2-B: Technique of the Y incision in the joint capsule is shown in the drawing.

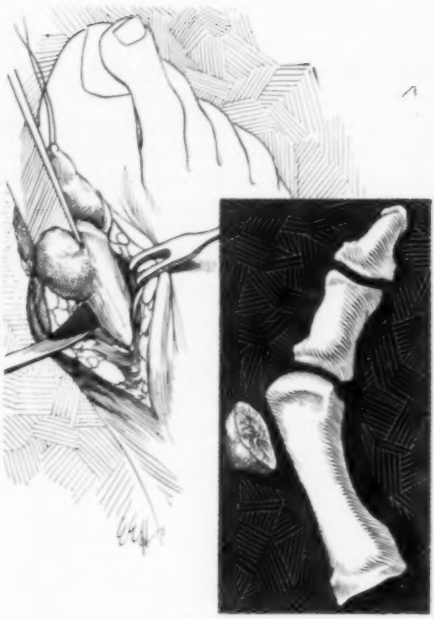


FIG. 2-C

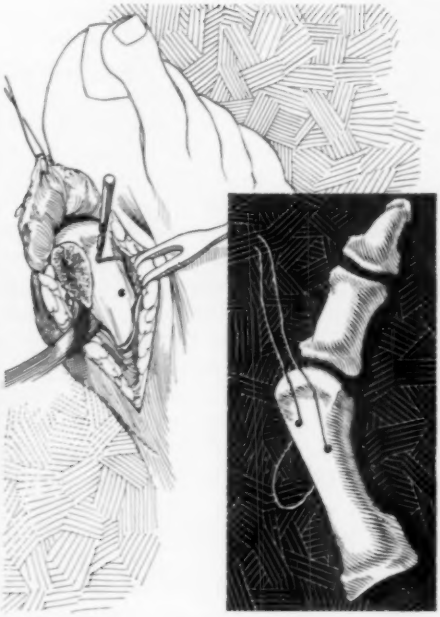


FIG. 2-D

Fig. 2-C: Illustration shows removal of the exostosis.
Fig. 2-D: Placement of the drill holes is shown in artist's drawing.

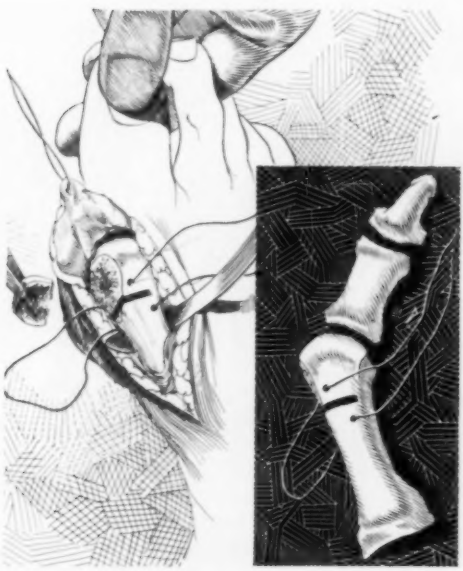


FIG. 2-E

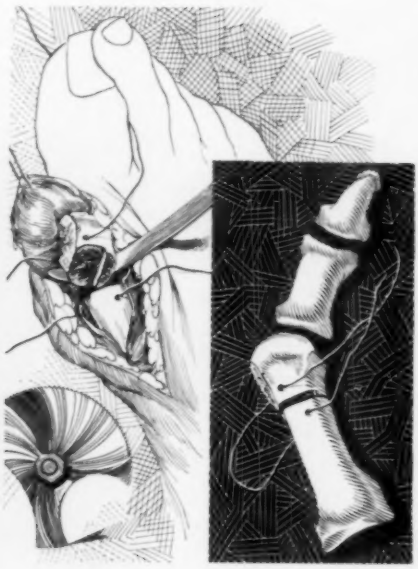


FIG. 2-F

Fig. 2-E: Drawing shows the double osteotomy cut.
Fig. 2-F: Completion of the proximal osteotomy cut is illustrated.

The neck and shaft of the metatarsal are then stripped subperiosteally (Fig. 2-C). The lateral capsular attachments are not disturbed for these structures are the only remaining source of blood supply to the metatarsal head. The exostosis is removed flush with the shaft of the metatarsal.

Two holes are drilled, one being one-half an inch and the other one inch from the articular surface (Fig. 2-D). The distal drill hole is slightly medial so that the holes will be in line when the lateral shift of the head is accomplished. Care is taken to place these holes perpendicular to the metatarsal shaft. A No. 1 chromic catgut suture is placed through the holes by means of a ligature carrier or straight needle.

A double incomplete osteotomy is then done three-quarters of an inch from the articular surface between the drill holes and perpendicular to the shaft (Fig. 2-E). The thickness of bone between the two cuts depends upon the amount of shortening of the metatarsal that will be necessary to relax the contracted lateral structures. Usually about two to three millimeters (one-eighth of an inch) of bone is removed. The size of the lateral spur depends upon the amount of metatarsus primus varus to be neutralized by the lateral shift of the metatarsal head. In a moderate deformity one-sixth of the width of the shaft is left to form the lateral spur, while in a severe deformity one-third of the shaft remains. The osteotomy is completed proximally with a thin saw blade (Fig. 2-F).

Then the metatarsal head is shifted laterally until the lateral spur locks over the proximal shaft (Fig. 2-G). The head is angulated slightly laterally so that its articular surface parallels the axis of the second metatarsal. Slight plantar displacement or angulation is desirable at this stage for reasons that will be discussed. The suture is tied, giving surprising stability to the osteotomy site.

Medial capsulorrhaphy is carried out with the hallux held in slight overcorrection (Fig. 2-H). Chromic 00 is commonly used for the capsular repair. The toe is then released and examined. It should stay in complete correction as a result of the capsulorrhaphy. If it does not, the distal capsular flap should be shifted farther proximally and resutured.

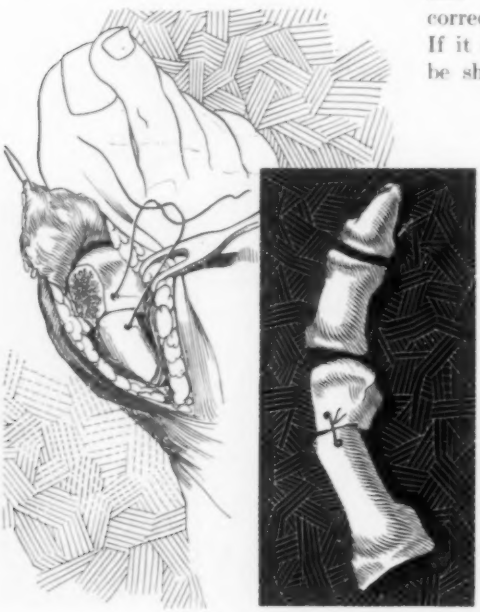


FIG. 2-G

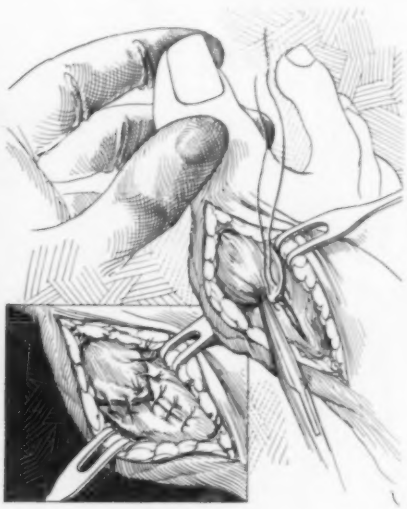


FIG. 2-H

Fig. 2-G: Lateral displacement of the metatarsal head and suture stabilization are shown in drawing.
Fig. 2-H: Drawing shows technique of capsular repair with toe held in slightly overcorrected position.

Postoperative splinting will not provide correction that is not obtained at the operating table.

Splints made of padded tongue depressors are applied with the toe in slight overcorrection and in 5 degrees of plantar flexion, to avoid dorsal displacement or angulation at the osteotomy site (Fig. 2-I). This splint is worn for ten days. Following suture removal, a short walking cast is applied to the leg, incorporating the great toe. Again, care is taken not to displace or angulate the osteotomy site dorsally.

Technical Failures

If the osteotomy is done too far proximally, the site will be in the compact bone of the shaft rather than in the cancellous bone of the neck. The fragments take longer to heal and it is more difficult to maintain the toe in the desired position.

Displacement of the osteotomy from the sutures breaking because of rough handling or from incorrect application of the splint or cast may occur.

An unstable osteotomy because of loose suturing or communication of the drill holes with the osteotomy site, if either is not perpendicular, may result. An uneven or asymmetric lateral spur on the distal fragment may also be a factor in instability.

Another technical failure that has been noted is incomplete correction of the metatarsus primus varus because of neglect to laterally angulate the head of the metatarsal. The head of the metatarsal should be lined up with the second metatarsal, so that the metatarsus primus varus is corrected where it is significant — at the metatarsophalangeal joint.

Dorsal angulation or displacement of the metatarsal head should be avoided. The incidence of postoperative second or third metatarsalgia was greater if this situation existed.

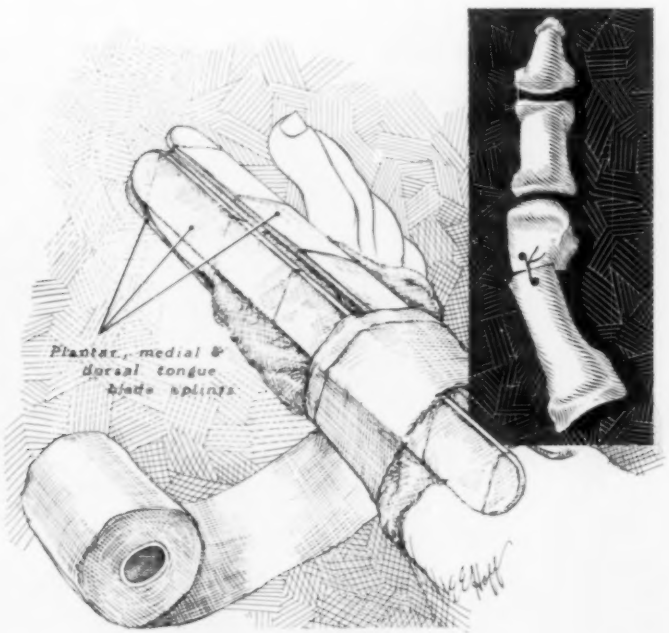


FIG. 2-I

Application of the dressing made from tongue depressors is shown in artist's illustration.

Incomplete correction of hallux valgus because of an inadequate medial capsulorrhaphy may occur. If the arms of the Y capsular incision are carried too far proximally, the repair is more difficult because of the thinner tissues in that area.

Finally, there may be aseptic necrosis of the metatarsal head as a result of stripping of the lateral capsule.

POSTOPERATIVE COURSE

The walking cast is worn for four weeks. Then, if roentgenograms and clinical examination reveal healing, the patient immediately begins weight-bearing. Patients with bilateral involvement progress about as well as those in whom only one foot is involved. Comfortable shoes, well broken in, are worn until the swelling diminishes. Then the patient is allowed to wear any shoes that she desires.

FIG. 3-A

FIG. 3-B

Fig. 3-A: C. V. Preoperative photograph showing dorsal view of both feet.
Fig. 3-B: Preoperative photograph showing plantar view of both feet.

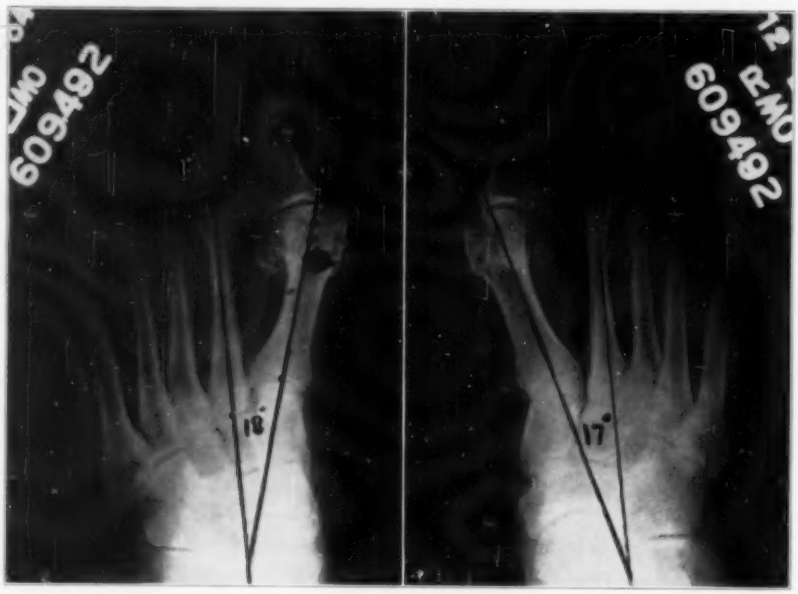


FIG. 3-C

Anteroposterior roentgenograms of both feet made before the operation.

C. V. (Figs. 3-A through 3-F). This woman was forty-five years of age when both feet were operated upon in December 1954. She complained chiefly of painful bunions on both feet of fifteen years' duration. She also had second metatarsalgia which did not disappear postoperatively. The metatarsal shortening was less than average, being four millimeters on the left foot and seven millimeters on the right. The osteotomy sites were in a neutral position with regard to plantar angulation. There was moderate metatarsophalangeal joint restriction bilaterally. The patient's clinical rating one year after surgery at the time of review of these cases was *excellent* for both feet. She was "partly satisfied" primarily because of the mild persistent metatarsalgia. She stated that she would advise others to have this operation. Her bunion pain was completely relieved and the cosmetic result was good. The change in the intermetatarsal angle from 18 degrees to 10 degrees on the left foot and from 17 degrees to 3 degrees on the right was considered excellent.

END-RESULT STUDY

The Sample

Of the patients upon whom more than 400 operations were performed fifty-nine

FIG. 3-D

FIG. 3-E

Fig. 3-D: Postoperative photograph showing dorsal view of both feet.
Fig. 3-E: Plantar view of both feet after the operation.

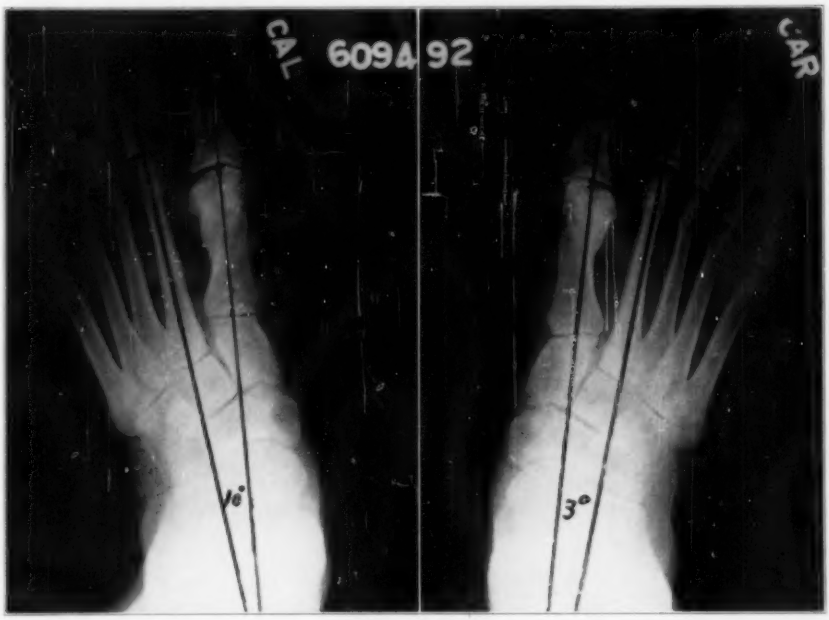


FIG. 3-F

Postoperative anteroposterior roentgenograms of both feet. Note that the sesamoid bones are now in normal position.

were examined, x-rayed and photographed in the fall of 1955. There were fifty-seven women and two men. The average follow-up time was eight years with a range of from one to twenty years. Forty-one patients had bilateral surgery and eighteen unilateral. Ninety per cent were operated upon for pain and deformity and 10 per cent for deformity alone.

Family History

Thirty-four patients (58 per cent) recalled a family history of bunions. Hardy and Clapham found a positive family history in 63 per cent of ninety-one patients with bunions and in only one of eighty-four controls. These figures, as well as the early onset of deformity in the majority of cases (Hardy and Clapham reported that, of their group, 46 per cent estimated that symptoms appeared before they were twenty years old) lend strong support to the theory of the hereditary and congenital basis of metatarsus primus varus and hallux valgus.

Age at Time of Surgery

The majority of patients operated upon were between thirty and fifty-five years of age, as shown in Chart I. Seven patients were sixty or older. The oldest patient, who was seventy-two years old, had an excellent result.

Average Duration of Preoperative Symptoms

This was determined to be 4.6 years in forty-one patients. However, in many cases the duration of the deformity was much longer.

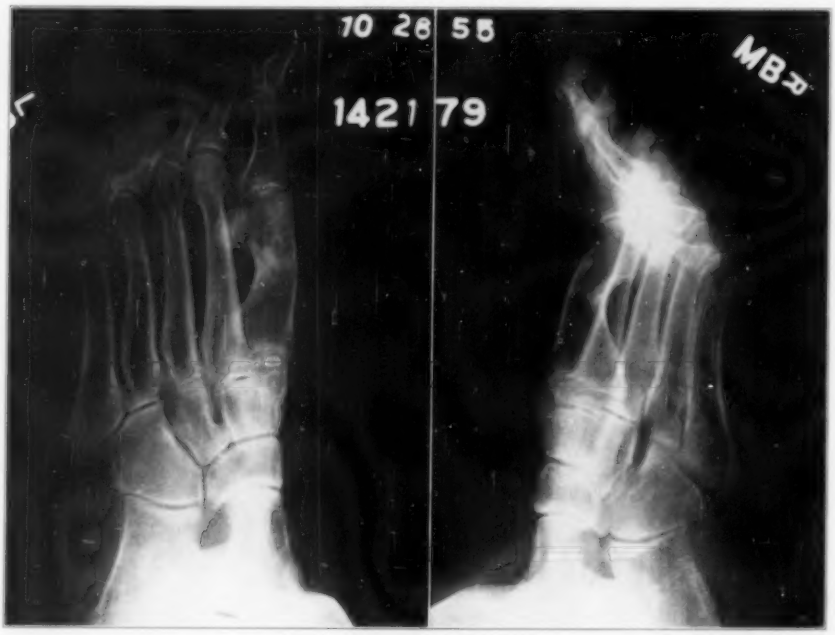


FIG. 4

Oblique postoperative roentgenograms showing marked plantar angulation of the osteotomy site. This patient experienced complete relief of preoperative second metatarsalgia which is felt may be because of the plantar angulation of 30 degrees shown.

Result Correlated with Age at Time of Surgery

No correlation between the results of the operations and the patients' ages at the time of surgery was found when comparisons were made with ages less than sixty. Results were *good* or *excellent* in 86 per cent of the patients under the age of sixty and in 50 per cent of those over sixty years of age. Results were *good* or *excellent* in 82 per cent of the operations in the entire series.

Subjective Result

Chart II shows the patients' responses to the question, "Are you satisfied with the result?" and lists their reasons for partial or complete dissatisfaction. Note that of twenty-six symptoms, metatarsalgia was given fourteen times, pain in the great toe six times, and recurrence of hallux valgus six times.

Objective Result

Chart III shows the surgeon's ratings of 100 operations. The excellent results were those with which both patient and surgeon were totally satisified. The cases rated *good* were those in which the patient had no pain but may have had slight recurrence of hallux valgus or more than usual limitation of joint function.

In those cases rated *fair* there was moderate recurrence, exostosis formation, metatarsalgia that developed or was worse after operation, or slight degenerative changes in the joint. In general, these patients reported a subjective rating of partially satisfied. In one instance of fibrous union in this series there was a frank infection of the wound. The patient in whom this occurred had a fair result, although from the clinical standpoint alone the result was excellent.

Eight of the nine poor results were mainly because of degenerative joint changes. These patients were all over forty years of age at the time of surgery. Two patients with late aseptic necrosis and four with hallux rigidus are included in these eight cases. Two patients with severe recurrence were seen, each of whom had medial instead of lateral angulation at the osteotomy site and increased metatarsus primus varus.

In general, there was close correlation between the patients' and the doctors' view of the result. Eighty-two per cent of the operations were rated *good* or *excellent* while patients were totally satisfied with 80 per cent of the operations. Two patients were only partly satisfied because of unrelieved second metatarsalgia but were rated *good* because relief of pre-existing metatarsalgia cannot be considered a prerequisite of a satisfactory result. (However, see the section dealing with metatarsalgia to follow.)

Relief of Bunion Pain

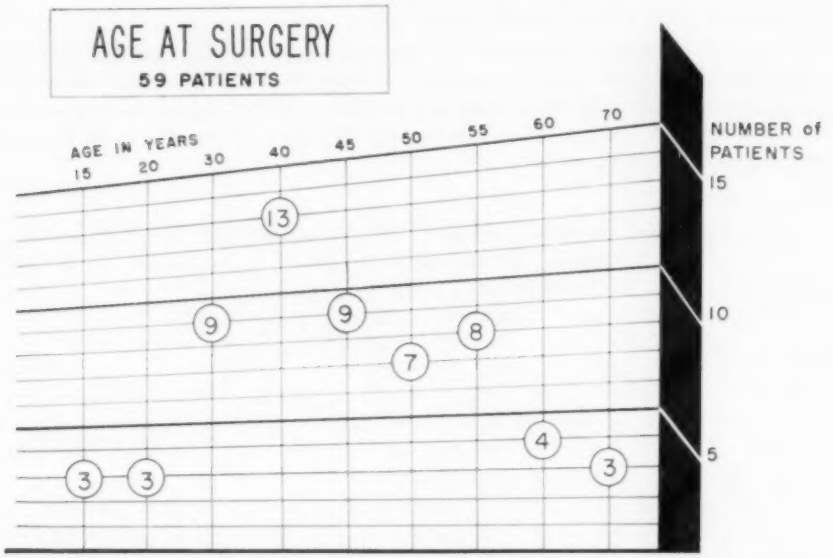
Six of the 100 feet were not relieved of bunion pain; 84 per cent were relieved, and in 10 per cent pain was not present before or after surgery. Of the six feet, one had hallux rigidus, two had no correction of the metatarsus primus varus and only partial correction of the hallux valgus, and three had recurrence of hallux valgus. Two of these had an increase in metatarsus primus varus because of medial displacement and angulation at the osteotomy site.

Recurrence of Hallux Valgus

In general, patients failed to recognize slight recurrence, as shown in Chart IV, and were often satisfied even with moderate recurrence if the pain were relieved.

Length of Convalescence

Sixty-two per cent of the patients resumed normal activities after three months and 66 per cent wore regular shoes (Chart V). The investigators found that often the prolonged rehabilitation was a result of minor or unrelated conditions. In general, a patient fully recovers in from three to four months following this type of surgery and



AVERAGE DURATION of PREOPERATIVE SYMPTOMS • 4.6 YRS. in 41 PATIENTS

CHART I

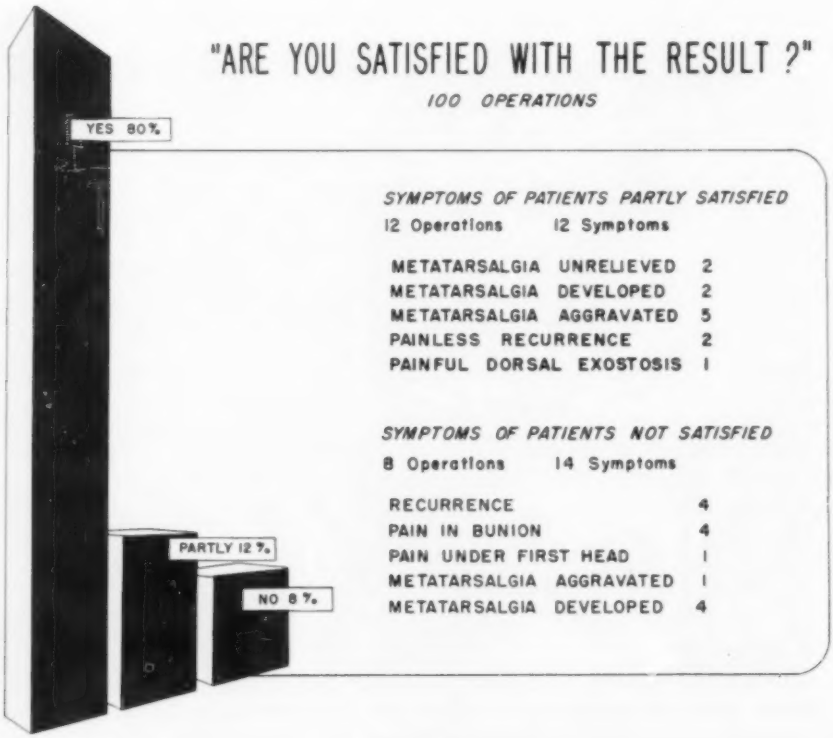


CHART II

often much sooner. Age, circulatory status, persistent swelling, and personal inclination were factors which were found to affect the length of convalescence. It should be noted that patients were requested to comment on *full* activities and the wearing of *normal* shoes, both of which were often limited preoperatively, sometimes by conditions unrelated to the feet.

Correlation of Result and Function of the Metatarsophalangeal Joint

There was a high correlation between the clinical result and adequate range of motion of the metatarsophalangeal joint (Chart VI). In 86 per cent of those feet with excellent results and in 75 per cent of those with good results, there was motion that was normal or nearly so. A few results were listed as *good* or *excellent* despite moderate or severe restriction of motion, because of preoperative limitation associated with severe deformity in some instances, and equal restriction on the unoperated side in others.

In general, patients felt that there was no stiffness if they had no dorsiflexion deformity and at least 40 degrees of dorsiflexion.

Correlation of Correction of Metatarsus Primus Varus with Result

As is evident from Chart VII, most of the good and excellent results were accompanied by a significant decrease of the intermetatarsal angle with a residuum of less than 10 degrees of metatarsus primus varus. In only 69 per cent of the 100 feet was this angle change found. The patients with little or no angle change were little improved by the osteotomy except for the slight shortening. However, these patients were often helped by the exostosectomy and the medial capsulorrhaphy. When the intermetatarsal angle was increased, the results were unsatisfactory except in two cases (7 per cent of those with good results) in which there was a good clinical result in spite of a slight increase in metatarsus primus varus.

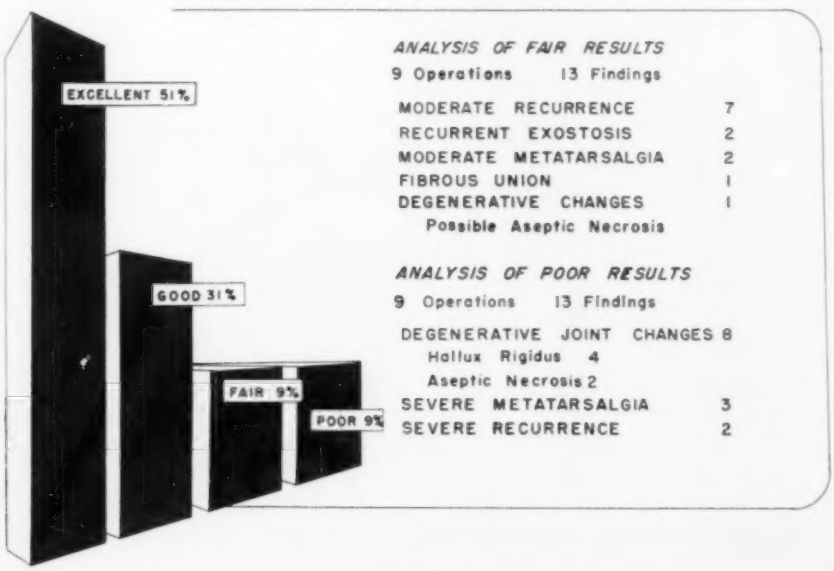


CHART III

The findings shown in Chart VII give evidence that to obtain a lasting result, the metatarsus primus varus must be corrected. Eighty-seven per cent of the patients in whom this correction was obtained had a good or excellent result, and most of these were excellent (44 per cent *excellent*, 20 per cent *good*). Only six patients who had a good angle change did not have a satisfactory result.

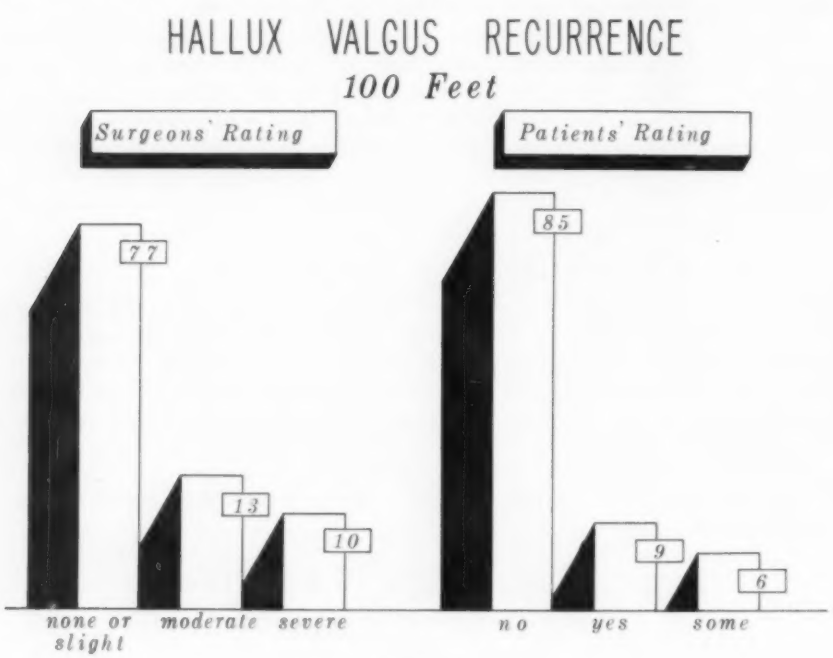


CHART IV

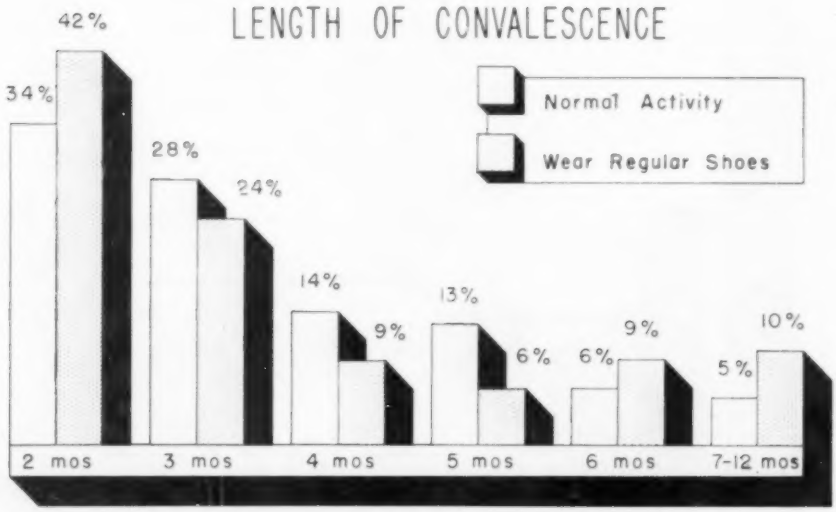


CHART V

Seventy-two per cent of the patients with little or no intermetatarsal angle change had a good or excellent result and most of these were good (ten *good*, seven *excellent*).

Note that the chart expresses percentages within the groups of excellent, good, fair, and poor, referring to clinical results. We found that of fifty-one feet with excellent results, forty-four had a significant angle change and seven had little or no angle change. Of the thirty-one feet with good results, twenty had a significant angle change, nine had little or none and two had an increase in the intermetatarsal angle. Of the nine feet with fair results, three had significant angle change, four had little or none, and two had an increase in the angle. Of the nine feet with poor results three had significant angle change, two had little or none, and four had an increase in the intermetatarsal angle.

Hardy and Clapham found in their statistical survey that the most striking of all correlations was the degree of hallux valgus with the size of the intermetatarsal angle. The correlation coefficient between them in both the control and morbid groups was 0.71 and the average value in the morbid group was 4.5 degrees higher than that in the control group. In addition, the correlation was small between the divergence of the second to fifth metatarsals and the incidence of hallux valgus. Statistically this may be interpreted that although splay-foot is often accompanied by hallux valgus, it is caused not by the splaying *per se* but only by the metatarsus primus varus.

Second Metatarsalgia

Most papers on hallux valgus have ignored the high incidence of metatarsalgia in the preoperative symptoms of the patient with bunions. In 64 per cent of the feet in

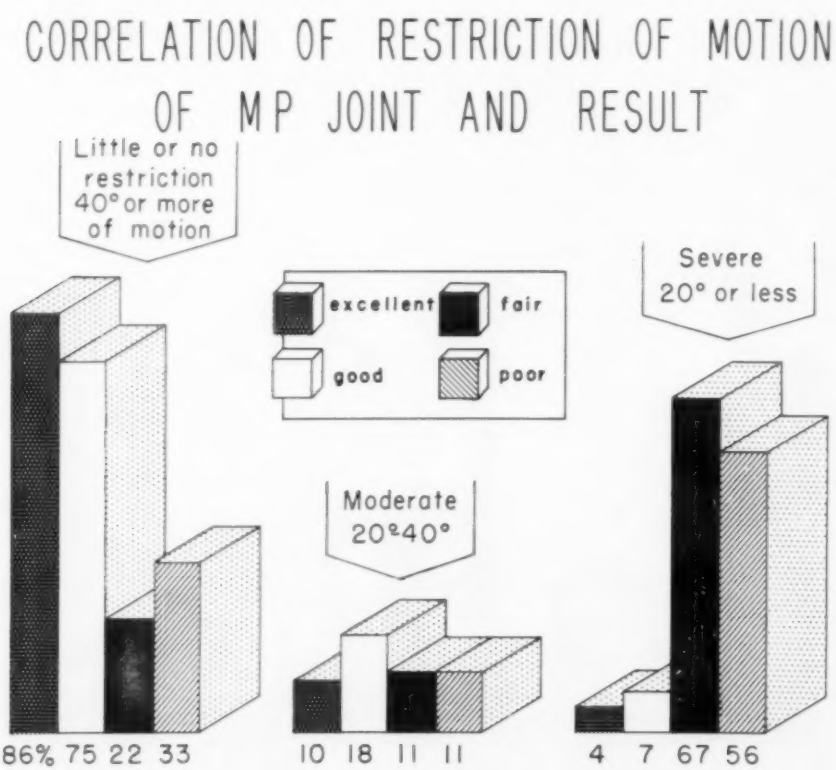


CHART VI

this series there was metatarsalgia. Also, statistical studies of results have usually failed to discuss this distressing symptom. The effect of a successful operation may be nullified by the onset or persistence of metatarsalgia. Hardy and Clapham considered the matter briefly and found a low correlation of anterior metatarsalgia with numerous other foot abnormalities. However, there was a highly significant difference in the ergometric measure of the power of the toe flexors (twenty pounds in those with the symptoms of anterior metatarsalgia as against twenty-eight pounds in those without).

In reviewing our cases, we found that of the sixty-four feet with second metatarsalgia before surgery, six were improved and thirty-six were relieved. Twenty were not relieved and in two the pain was aggravated. After surgery, pain developed in ten other feet that had had no preoperative metatarsalgia. In seven of the twelve in which it developed or was aggravated, the pain was mild and non-disabling. Five had severe pain. One of the latter group required excision of the metatarsal head.

The authors' awareness of the possible relationship between first metatarsal shortening and second metatarsalgia has prompted the careful review of this problem. As far as we can determine, there is no correlation. This is in accord with the findings of Harris and Beath, who in their excellent statistical survey of over 1,300 individuals, concluded that "a short first metatarsal seldom, if ever, is the cause of foot disability."

In this series, in fifteen feet with no second metatarsalgia, there was an average of 6.6 millimeters of first metatarsal shortening postoperatively. There was an average of 7.1 millimeters of metatarsal shortening in eleven feet in which metarsalgia had been relieved or improved, and in nineteen feet in which the metatarsalgia was not relieved,

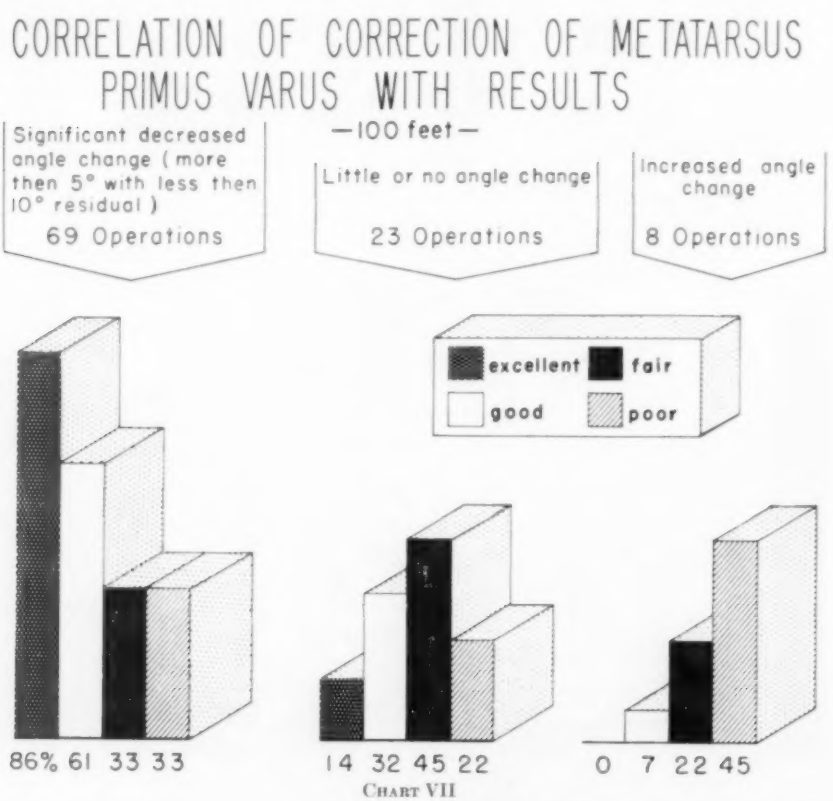


CHART VII

was aggravated, or developed, there was an average of 8.0 millimeters of metatarsal shortening. Measurements were made by setting up a ratio between the lengths of the second metatarsal as shown in the preoperative and postoperative roentgenograms, and the length of the first metatarsal as shown in the preoperative roentgenogram. From this was derived what the length of the first metatarsal would have been if not shortened. By substituting the measurement of the first metatarsal in the postoperative roentgenogram, the amount of shortening was derived. These measurements are difficult at best and on some roentgenograms impossible to determine. The 8.0-millimeter average includes one patient with fibrous union in whom the shortening was 15 millimeters. Without this case, the average for the group of those in whom metatarsalgia developed or was aggravated would be 6.2 millimeters.

In addition to the fact that we could find no correlation between first metatarsal shortening and second metatarsalgia, there is the evidence of Hardy and Clapham that the first metatarsal in hallux valgus is unduly long. The mean difference between the lengths of the first and second metatarsals in the morbid group was four millimeters; in the control group it was two millimeters. Statistically this was highly significant. Some surgeons, including the authors, have felt that to be the case and that some method of shortening is desirable.

If first metatarsal shortening did not cause postoperative second metatarsalgia in our patients, what did? One case gave us the key to the probable explanation. This patient had an unsuccessful operation because the metatarsal head displaced medially and the hallux valgus recurred. However, the severe preoperative metatarsalgia disappeared. Note that, as shown in Figure 4, the first metatarsal is angulated plantarward at the osteotomy site.

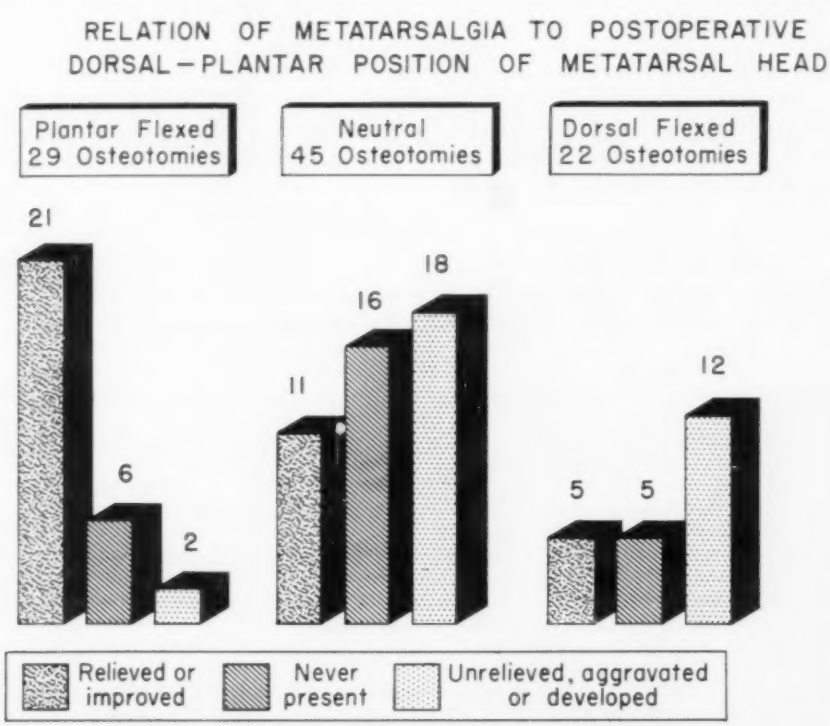


CHART VIII

The entire series was then analyzed from this point of view, and the results are shown in Chart VIII. The implication is clear that if the first metatarsal head is depressed at the osteotomy site, the second metatarsalgia is very likely to be relieved or improved, and if the metatarsal head is elevated, the reverse will be true. The presumptive explanation for this is that if the first metatarsal takes its normal share of the weight, the second metatarsal will not be overloaded. No patient in whom the metatarsal head was depressed developed pain under the first metatarsal. For many years, the senior author has insisted that the toe be splinted in slight flexion and this study lends justification to this view.

Pain, Deformity, and Cosmetic Results

Pain, deformity, and shoe problems were the complaints in 90 per cent of the patients. Ten per cent were operated upon for cosmetic reasons alone. The authors do not hesitate to advise correction of the unsightly deformity of hallux valgus even in the adolescent, and in fact are inclined to suggest that severe deformity be corrected before it becomes symptomatic. None of our patients operated upon for cosmetic reasons developed symptoms.

Patients reported changes in shoe size after fifty-five operations. Length increased in fourteen feet and decreased in twelve. Width increased in fourteen feet and decreased in twenty-nine.

Patients felt that fifty-three of the operations resulted in a great toe that was shorter than that before surgery, but no patient felt that this was a disadvantage. In fact, many felt that the length looked more normal after surgery.

Ninety-two per cent of the patients stated that they would advise this operation. A few had some reservations, mostly concerned with who the surgeon would be and the length of convalescence.

SUMMARY

Over 400 operations have been done for hallux valgus with metatarsus primus varus in which a distal first metatarsal osteotomy with lateral displacement and angulation of the head was used. This operation was not done in patients who had simple hallux valgus without metatarsus primus varus.

Fifty-nine patients who had had 100 operations were examined and x-rayed in 1955. The results were generally satisfactory in eighty-two per cent of the operations.

It is felt that this operation has merit when done correctly in a suitable patient. The authors plan to continue the use of this operation, and feel that the results can be improved by attention to technical details and by proper selection of patients.

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DISCUSSION

Dr. George Hammond, Boston, Massachusetts: In selecting an operative plan for the correction of hallux valgus, a procedure should be chosen which will correct the basic pathological cause. Any operation falling short of this goal is inadequate and will yield disappointing results.

In the clinical and roentgenographic examination of a patient with hallux valgus, the deformity of a first metatarsal is frequently overlooked or disregarded. Most patients with moderate to severe hallux valgus will show an adducted or varus position of the first metatarsal of over 10 degrees. This metatarsal malposition as a basic fault has not received the recognition it deserves. It is not logical, as Dr. Mitchell has stated, to attempt correction of the great toe and allow the metatarsal deformity to persist.

Another consideration is the first metatarsophalangeal joint which should be preserved in operations for hallux valgus if it has good function. A good joint should not be destroyed simply because it is deformed, and reconstruction will yield better results than bone excision operations.

Several authors have stressed that correction of any significant metatarsus primus varus (10 degrees or more) is essential to a permanent correction of hallux valgus and have introduced operative procedures to remedy this deformity. In view of the general agreement that the varus deformity of the first metatarsal is important in hallux valgus, it is puzzling that so few operations are done to relieve the inward deviation of this bone.

In 1945, Dr. Mitchell introduced an osteotomy of the distal metatarsal shaft, correcting the varus deviation at the level of bone section, and now he adequately supports this procedure with his twenty years of experience with 400 osteotomy-bunionectomies and by the well documented end results of 100 operations in fifty-nine patients. The Mitchell operation fulfills all of the requirements of a good operation for moderate and severe cases of hallux valgus and metatarsus primus varus.

The simplicity of the technique cannot be overemphasized. However, the details of the operation must be carefully adhered to, and a few warrant recapitulation:

1. The lateral capsular attachments of the first metatarsal head must not be elevated, or there will be danger of avascular necrosis;

2. Adequate correction of the metatarsus primus varus is dependent upon sufficient lateral displacement of the metatarsal head and slight medial angulation of the fragments at the site of osteotomy;

3. Plantar angulation of the fragments should be avoided to prevent postoperative metatarsalgia.

In my own experience, this operation when properly performed has consistently yielded gratifying results, both subjectively and objectively. The lasting correction of the deformity of the great toe and metatarsal has been impressive. In addition, most of the splaying is also remedied with resultant narrowing of the fore part of the foot. The patients did not complain of the six to seven weeks of splinting when they understood the problem and particularly after they obtained enduring relief.

Dr. Earl D. McBride, Oklahoma City, Oklahoma: Dr. Mitchell rightly has called attention to the causal relation of metatarsus primus varus to hallux valgus and bunion deformity. The two principal functions of the great toe are support and locomotion. Normal skeletal stability of the numerous bones of the foot depends on musculoligamentous intermedium. Dr. Mitchell attributes the hallux valgus to metatarsus primus varus, but what is the cause of metatarsal deformity? I am of the opinion that it is of hereditary genesis but it does not necessarily follow that hallux valgus is an inevitable result. Many feet with metatarsus primus varus do not have hallux valgus. We must consider the foot as a whole, not just the first metatarsal. Metatarsus primus varus is an adaptive deformity due to muscle contraction, and is not caused by the anthropoid shape of the cuneiform articulation.

It is often found that the mother or other close relative of the patient had bunions. However, hallux valgus is not often found in people who do not wear shoes. For example, in Japan and other countries where clogs are worn and held to the foot by a strap between the first and second toe, the incidence of hallux valgus is extremely low. Likewise, hallux valgus occurs less in men, who wear broad-toed shoes, than in women, who pinch their toes in shoes. Mechanically, the first metatarsal is a long lever arm with its fulcrum at its proximal end where it joins the second metatarsal. The distal end of this power arm has no stabilizing resistance except that of joint capsular enclosure. The proximal end of the first metatarsal is subject to all the stresses of the other tarsal and metatarsal structures as influenced by tension of the peronaeus longus and the anterior and posterior tibial tendons. Alteration of the shape of the cuneiform bone will not correct metatarsus primus varus. When the foot is enclosed in a shoe, the great toe is restrained from responding to forces of the abductor hallucis but continues to respond to the strong adductor hallucis forces with an outward pull on the proximal phalanx of the great toe. The head of the first metatarsal begins to press inward, starting valgus deformity of the toe. Overdevelopment and contraction of the adductor follows, eventually resulting in bursitis and degenerative joint changes with all of the disfiguring results of hallux valgus and bunion deformity. The rotundity of the first metatarsal head tends to ride medially away from the sesamoids and separate from the fascial ligamentous ensemble which bind the outer metatarsals together.

Hallux valgus should be corrected by the operation best suited to the case. More attention should be given the foot of the adolescent. Here simple tenotomy of the adductor tendon, forced manipulation, and

attentive follow-up will prevent sequelae. Many adults do not seek surgical relief until after they are fifty or sixty years old, when there are severe irreversible joint changes. When the joint changes are not irreversible it would seem much more rational to attack the problems directly at the point where the resisting forces are producing the deformity. When articular degeneration has become severe and hallux rigidus and other complications are a threat to correction, the indirect attack of excision or osteotomy is more often indicated.

Dr. Mitchell's osteotomy is ingenious in that it provides control to the unstable metatarsal head. As in other osteotomies, capsular and articular trauma which often aggravate degenerative processes should be avoided. Dr. Mitchell deserves much credit for his painstaking follow-up statistics on 100 cases and I congratulate him on the high percentage of good results. I am pleased that Dr. Mitchell has called attention to the problem of metatarsalgia. In any event, no foot should be operated upon for hallux valgus and bunion without thorough consideration of the foot as a whole. Hammer-toe or claw-foot, especially of the second toe, is often a problem demanding extreme caution. I gain the impression from Dr. Mitchell's statistics that shortening of the first metatarsal because of the osteotomy did not contribute very greatly to metatarsalgia except when the metatarsal heads were involved in the clinical picture preceding operation.

DISCUSSION

Central Fractures of the Acetabulum

(Continued from page 16)

is justification for this—in fact, some hips will be poor whether they are treated by open or closed methods

Our follow-up study of severe central acetabular fractures with varying degrees of intropelvic protrusion, indicates that we should not be too discouraged with closed treatment.

Our routine has been to carry out an initial manipulation under anaesthesia, if possible, or whenever the patient's condition has stabilized. The extremity is then placed in suspension with skeletal traction through the lower portion of the femur or tibial tubercle. Early motion of the hip is begun, and weight-bearing is delayed for three to four months. In many instances the essential reduction has been accomplished—that is bringing the head under an intact superior quadrant. When this is impossible, open reduction is planned.

There will be instances too, when open reduction will fail. At least by open reduction the acetabular stock will be left in better workable position for arthroplasty.

I offer the following figures to take the pressure off open reductions, or to put closed treatment in a little more favorable light. We have follow-up information on thirty-one severe central fracture-dislocations with an average follow-up period of four years. Twenty-three were treated by closed methods, thirteen resulted in good hips, some were excellent. Eight of the thirty-one hips were treated by open reduction, one was excellent, five were good (two of these had initial cup arthroplasties), and two were poor.

Again this is a small series. It indicates a more favorable prognosis to closed treatment. It is safe.

Dr. Alfred M. Okelberry, Salt Lake City, Utah: We at the Salt Lake Clinic also have seen an increase in severe acetabular fractures in recent years. There is apparently a place for open reduction when closed procedures do not give the desired results. Our first open reduction was done in 1951 after traction with actual distraction of the joint had failed to restore the medial wall of the acetabulum. The good result in this patient gave us reason for optimism in the treatment of these injuries. The classification presented by Knight and Smith is certainly interesting and helpful in the study of these fractures and in planning for closed reduction or for an operative approach when surgical treatment is indicated.

(Continued on page 120)

Shortening of the Metatarsal Shaft in the Treatment of Plantar Keratosis

An End-Result Study*

BY NICHOLAS J. GIANNESTRAS, M.D., CINCINNATI, OHIO

From the Fracture and Orthopaedic Department of the Good Samaritan Hospital, Cincinnati

The term *plantar wart* has been used to describe almost any and every painful lesion found on the plantar aspect of the foot. Such lesions are tender upon lateral compression and are covered by a heavy layer of thickened epidermis. No attempt has been made to differentiate clinically or microscopically between the true verruca plantaris and the condition which the author suggests be termed *plantar keratosis*. This simple differentiation would spare many people with plantar keratosis from undergoing several types of treatment, most of which are painful, and finally from a recurrence of the lesion with its attendant symptoms.

The pain associated with plantar keratosis is frequently severe and in many instances quite disabling. Many patients are almost desperate in their attempts to secure relief. The pattern of treatment is often typical. First the metatarsal pad is used. If this does not relieve the condition fulguration or destruction of the lesion with chemicals usually follows. Since the condition frequently persists or recurs, roentgenotherapy, sometimes in excess, is prescribed as the patient shifts from the physician to the chiropodist, to the so-called podiatrist, and then to another physician. By this time some patients despair of any further treatment and learn to live with the lesion as best they can. Others undergo excision of the keratosis, which usually recurs, or finally submit to a skin-grafting procedure with its prolonged period of disability. Even after grafting, recurrence of the lesion has been known to take place. In some instances the soft-tissue changes from repeated chemical and electrical cauterization and tissue-destroying irradiation or both are so extensive that trophic ulcers result, and full-thickness pedicle grafts are necessary. It is indeed unfortunate that the lack of differentiation between the two lesions subjects the patient to this gamut of treatments. A careful follow-up study would demonstrate that a high percentage of poor end results follows cauterization, roentgenotherapy and local excision. These different tissue-destroying methods are mentioned only to decry their use and to stress the plea for more careful distinction between the verruca plantaris and the more frequently occurring but poorly treated plantar keratosis. All of us are guilty of treating this lesion lightly. To the individual suffering from it, however, it is disabling.

DIFFERENTIAL DIAGNOSIS

Clinically, the true plantar wart is an extremely vascular, papillomatous growth which bleeds profusely upon more than slight trimming. It is found on the plantar aspect of the foot, both on the weight-bearing and the non-weight-bearing surfaces, in children as well as in adults. The true plantar wart resembles the plantar keratosis only in that direct pressure as well as lateral compression of the lesion produces pain. The true verruca plantaris responds well to any type of tissue-destroying therapy, whether it be electrical, chemical or irradiative.

Microscopically, the verruca plantaris is entirely different from plantar keratosis. As

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 30, 1957.

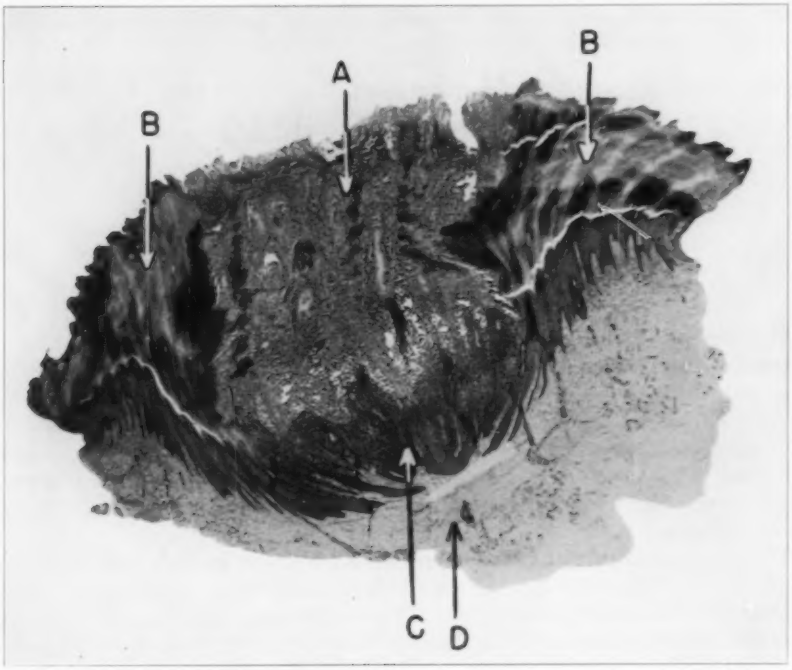

FIG. 1

Low-power photomicrograph showing a section of verruca plantaris. *A:* Hyperplasia of the squamous epithelium; *B:* lateral hyperparakeratosis; *C:* hypertrophied and elongated rete pegs in verrucose fashion; and *D:* normal-appearing corium.

seen in the photomicrograph (Fig. 1) there is central hyperplasia of the squamous epithelium surrounded by severe hyperparakeratosis. The rete pegs are elongated and appear to spread outward from the center in verrucose fashion. There is increased vascularity throughout the central portion of the lesion. The corium is normal in appearance.

The plantar keratosis, however, is almost invariably found on the plantar aspect of the weight-bearing portion of the fore part of the foot underlying one of the metatarsal heads or the metatarsophalangeal joints. The symptoms, both subjective and objective, do not differ from those of the verruca plantaris except that when the keratosis is trimmed, a small, pearl-gray, avascular center is found. If the keratosis is of long duration and has undergone a plethora of treatments, small hemorrhagic-like areas may be found within this center, but no true blood vessels are seen. Furthermore, if there is bleeding when the keratosis is trimmed, it will be observed that it occurs at the periphery of the pearl-gray center and not throughout the lesion, as is seen in the verruca plantaris.

On microscopic examination of a plantar keratosis which has not been treated previously by chemical means, fulguration, or by roentgenotherapy, one finds an entirely different picture (Fig. 2-A). The epithelium in the central portion of the lesion is indented, and there is striking hyperkeratosis of the center in comparison with the marginal portions. There is localized elongation of the rete pegs, which extends into the corium, in contrast with the pegs underlying the marginal, normal portion of the skin. Throughout the greatly thickened stratum corneum, many small, shrunken nuclei can be seen. The corium does not show any abnormality. In a previously treated plantar keratosis (Fig. 2-B), the rete pegs are thickened and blunted in comparison with those underlying the marginal epithelium. Again, in the central area, the epithelium is hyperkeratosic and

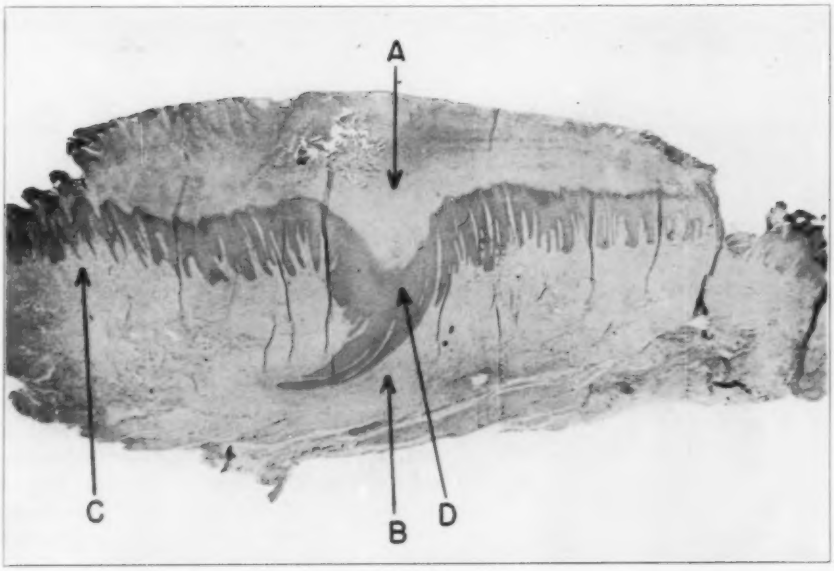

FIG. 2-A

Low-power photomicrograph showing a section of plantar keratosis not treated by roentgen rays. *A:* The plantar keratosis is seen in the v-shaped indentation of the epidermis and in hypertrophy of the epidermis; *B:* hypertrophied and elongated rete pegs directly under the keratosis. Note that the hypertrophy extends downward into the corium rather than upward toward the epithelial surface in comparison with Fig. 1; *C:* normal rete pegs and epithelium; *D:* greatly thickened stratum corneum with small and shrunken nuclei.

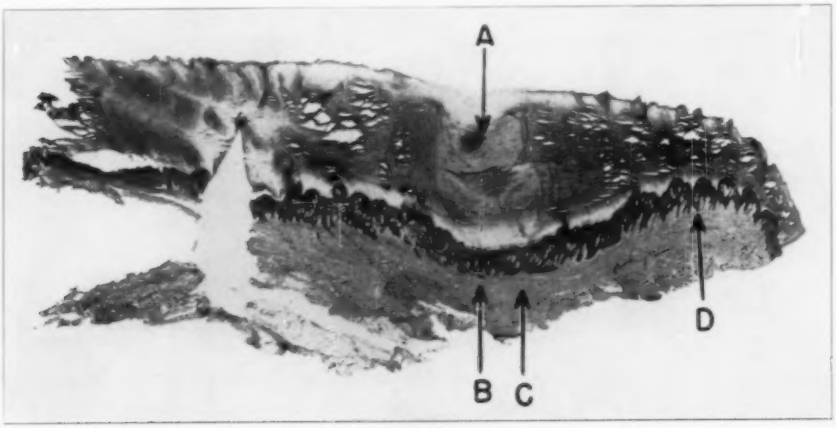

FIG. 2-B

Low-power photomicrograph showing section of a plantar keratosis previously treated with fulguration as well as with roentgenotherapy. *A:* Greatly thickened epidermis with indentation at the area of the plantar keratosis; *B:* rete pegs blunted and hypertrophied; *C:* directly beneath the keratosis the corium is composed of greatly hyalinized and comparatively coarse collagen with some loss of the normal vascularity; *D:* normal epidermis (note conformation of normal rete pegs).

indented. The corium directly beneath the center is composed of greatly hyalinized and comparatively coarse collagen, and is also relatively avascular. Under higher magnification the nerve trunks are often surrounded by a distinctly thickened sheath. Occasionally, hyalinization of the nerve fibers can be detected.

FIG. 3

Fig. 3. Roentgenogram made while the patient was standing. Note that the marker taped on the plantar keratosis is visible directly under the metatarsal head.

The average patient with a plantar keratosis comes to an orthopaedic surgeon usually after he has undergone various types of treatment other than surgery and, of course, has had recurrence of the lesion after each type of therapy. What then is the next step? Resection of the keratosis alone is not the answer as evidenced by the frequency of recurrence. Several years ago the author resected the metatarsal head overlying the plantar keratosis. Although there was relief from the pain, in many patients a cock-up or a hammer-toe deformity of the involved digit developed. The patients, of course, were dissatisfied and this operative procedure was discarded. Meanwhile, others had recommended resection of the plantar half of the metatarsal head but no true end-result study was presented. McElvenny reviewed his results of this procedure and found such a great number of recurrences that he discarded it. Metatarsal shortening, *per se*, for the treatment of plantar keratosis was first recommended by McKeever[3]. The shortening was performed at the junction of the head with the neck of the metatarsal. Although in the author's experience, the

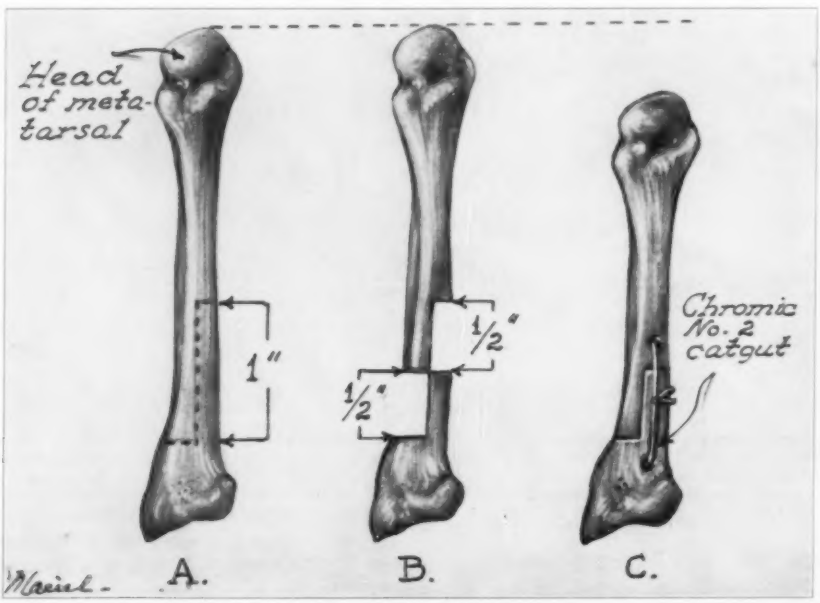

FIG. 4

Schematic drawings of operative procedure: *A:* drill holes outline step cut; *B:* osteotomy completed and portion of each tongue of step cut resected; and *C:* shortened metatarsal.

FIG. 5

Anteroposterior and oblique roentgenograms of left foot showing shortened third metatarsal six months postoperatively.

end results were satisfactory, in many patients limitation of function in the metatarsophalangeal joint developed. However, it is from this idea that the method of treatment which is about to be described, was developed.

The series of patients with which this report deals is a consecutive one. Each of these patients was examined and evaluated by the author and no patient who underwent this surgical procedure has been excluded from the study.

PLAN OF TREATMENT

Preoperative Examination

Following examination of the foot, anteroposterior roentgenograms are made while the patient is standing. A small lead marker is taped directly on the plantar keratosis (Fig. 3), in order to determine its exact location in relation to the overlying metatarsal head. If the lesion is not directly under the metatarsal head or the metatarsophalangeal joint, this surgical procedure is not recommended, since it will fail.

Operative Method

The operation consists in shortening the metatarsal shaft at its base. Since the texture of the bone at this level is more cancellous, callus formation and healing will occur more rapidly. The procedure is carried out under tourniquet ischaemia. The incision is made on the dorsum of the foot over the metatarsal above the keratosis, beginning at the tarsometatarsal joint and extending distally for approximately two and one-half inches. After the extensor tendons are retracted, the small muscles originating from the metatarsal shaft are gently reflected subperiosteally. Bunion retractors are then placed on either side of the metatarsal shaft to retract the small muscles and adequately expose the proximal

TABLE I

Patient	Previous Therapy	Date of Surgery	Metatarsal Involved	Result	Length of Follow-up (*Years*)	Comments
S.B.	Series of 6 roentgen-ray treatments	3- 6-51	Rt. 4th	Excellent	5¾	
A.B.	Excision, 6/50; series of roentgen-ray treatments, 9/50 and 12/50	7- 9-51	Lt. 4th	Excellent	5½	
D.I.	Multiple series of roentgen-ray treatments; one series of radium implantation; metatarsal pad; weekly trimming; there was severe scarring of tissues	3-14-52	Rt. 3rd	Failure	4¾	Recurrence, due primarily to insufficient shortening because of excessive scarring of tissues; disability not as severe
C.C.	Roentgenotherapy; metatarsal pad; block excision and skin graft, 12-10-48	3- 7-52	Lt. 3rd	Excellent	4¾	
D.R.	Roentgenotherapy; metatarsal pad; carbon dioxide snow treatment	3- 4-52	Lt. 3rd	Excellent	4¾	Patient was symptom-free for 18 months before keratosis under the region of the right medial sesamoid reappeared
		12- 2-52	Rt. 3rd	Excellent	4	
			Rt. medial sesamoid	Failure		
L.A.	Roentgenotherapy, 4/47; carbon dioxide snow treatment; metatarsal pad and trimming	5-12-52	Rt. medial sesamoid	Excellent	4½	Still wearing metatarsal pad because of resection of 5th metatarsal head
			Rt. 5th metatarsal head	Excellent	4½	
S.I.	Roentgenotherapy; carbon dioxide snow treatment; metatarsal pad and trimming	7-22-52	Lt. 3rd	Excellent	4⅓	
M.M.	Trimming and metatarsal pad	7-23-52	Rt. 2nd	Excellent	4⅓	
M.S.	Trimming and metatarsal pad	10- 3-52	Rt. 2nd	Excellent	4¼	
S.B.	During past 8 years, roentgenotherapy; two local excisions by electrocautery; infected draining keratosis developed	11-10-52	Lt. 3rd	Excellent	4⅙	Surgery performed in spite of draining sinus on plantar aspect; surgical incision healed, and draining sinus healed spontaneously
M.R.	One series of roentgenotherapy; trimming and metatarsal pad	12-26-52	Lt. 3rd	Failure	4	Insufficient shortening, although patient much more comfortable
E.G.	Ulcerating, infected keratosis; excessive roentgenotherapy	1- 2-53	Rt. 2nd	Excellent	4	Surgery performed in spite of ulcerated area on plantar aspect; spontaneous healing within 6 weeks
G.E.	Excision, trimming, and metatarsal pad	3-23-53	Lt. 2nd	Good	3¾	Plantar keratosis developed under third metatarsal head but foot quite comfortable in spite of it, according to patient; wears metatarsal pad in household shoes only

J.T.	Chemical cauterization; metatarsal pad and trimming	6–16–53	Rt. 3rd	Excellent	3½	
E.H.	Trimming and metatarsal pad for 12 years	7– 7–53	Rt. medial sesamoid	Excellent		
H.F.	Trimming and metatarsal pad for 20 years	7–21–53	Lt. 2nd	Good	3⅓	Patient able to wear high-heeled shoes for first time in many years; plantar keratosis developed under third metatarsal head; decided against further surgery
M.C.	Trimming and metatarsal pad	10–15–53	Lt. 2nd	Excellent	3⅙	
M.M.	Trimming and metatarsal pad	11–30–53	Lt. 3rd	Excellent	3 1/12	
D.F.	Trimming and metatarsal pad	12–10–53	Rt. 2nd	Excellent	3	
K.W.	Infected keratosis; patient had mild diabetes	12–10–53	Lt. 2nd	Excellent	3	
S.C.R.	Trimming, metatatarsal pad and roentgenotherapy	7–10–54	Rt. 2nd	Excellent	3½	Plantar keratosis developed under left third metatarsal; surgery had subsequent excellent results
			Lt. 2nd	Good	3½	
		7–15–54	Lt. 3rd	Excellent	2½	
H.V.	Four series of roentgen-ray treatments; local excision on 2 occasions; metatarsal pad; special shoes	7–19–54	Lt. 2nd	Excellent	2½	
S.E.	Pad; trimming and roentgenotherapy	9–13–54	Rt. 2nd	Excellent	2¼	Patient also had rheumatoid arthritic feet with hammer-toe deformities
			Lt. 2nd	Excellent		
H.F.	Electrical excision, roentgenotherapy, special shoes, and pad	9–28–54	Rt. 3rd	Good	2¼	Keratosis developed under second metatarsal head; patient to have shortening of second metatarsal
V.M.	Roentgen-ray therapy; trimming; pad; chemical cauterization	6–14–54	Lt. 3rd	Excellent	2½	
M.R.	Electrical excision; 3 series of roentgen-ray therapy during past 15 years	1–10–55	Lt. 2nd	Excellent	2	
[illegible]	Two series of roentgen-ray therapy, metatarsal pad, and trimming	2– 8–55	Rt. 2nd	Excellent	2	
E.H.	Metatarsal pad and trimming	5–13–55	Lt. 2nd	Excellent	1½	
			Rt. 2nd	Excellent		
M.M.	Metatarsal pad and trimming	6–30–55	Lt. 3rd	Excellent	1½	
			Rt. 2nd	Excellent		
R.N.	Novocain infiltration; metatarsal pad and trimming; xylocaine infiltration	9–29–55	Lt. 3rd	Excellent	1¼	
T.L.	Radium implantation roentgenotherapy; acid cauterization, special shoes and pad	10–31–55	Rt. 3rd	Excellent	1¼	
			Lt. 3rd	Excellent		

FIG. 6-A

FIG. 6-B

Fig. 6-A: Preoperative photograph showing plantar keratosis under third metatarsal head.
Fig. 6-B: Photograph of same foot one year after the operation.

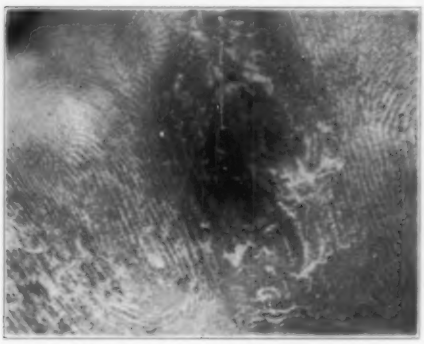

FIG. 7-A

FIG. 7-B

Fig. 7-A: Infected plantar keratosis with chronic trophic ulcer as a result of excessive irradiation is shown in photograph.
Fig. 7-B: Photograph of same foot twenty months postoperatively.

two-thirds of the shaft. With a bit one-sixteenth of an inch in diameter inserted in a small pistol-grip hand drill, a series of holes is made, and a one-inch step cut is outlined (Fig. 4, *A*). A thin osteotome one-half inch wide, is used to complete the step cut. Gentleness is of utmost importance in completing the osteotomy. Following this, with the use of a sharp, double-action rongeur, one-half an inch of each tongue of the step cut is resected, thus shortening the metatarsal (Fig. 4, *B*). With the same drill, a hole is made through the dorsal cortex of the distal and of the proximal fragment of the metatarsal in a slightly oblique fashion with the obliquity toward the open end of each fragment to permit the passing of the needle and the suture with greater ease. A double No. 2 chromic catgut suture is passed through the two drill holes and the two bone ends are pulled together (Fig. 4, *C*). The shortening of the metatarsal should be at least one-half an inch. If one finds it difficult to pull the two bone ends together, and this does occur in those instances in which there is a good deal of tissue fibrosis, a Kocher's forceps can be applied around the distal fragment and the shaft pushed proximally gently while the suture is being pulled together and tied. Shortening the metatarsal less than the prescribed amount will lead to failure of the procedure.

FIG. 8-A

FIG. 8-B

Fig. 8-A: Photograph showing plantar keratosis under third metatarsal head.

Fig. 8-B: Postoperative appearance of foot fifteen months later is shown in photograph. Plantar keratosis developed under second metatarsal eighteen months after the operation.

FIG. 9-A

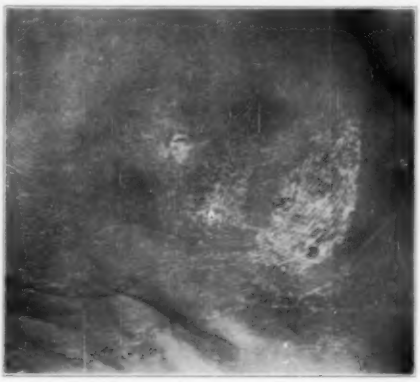

FIG. 9-B

Fig. 9-A: Photograph shows infected plantar keratosis under second metatarsal. The patient had mild diabetes.

Fig. 9-B: Photograph of same foot three months postoperatively. Result was excellent when the patient was last seen.

Upon completion of this portion of the operation, inspection of the plantar aspect of the foot will frequently reveal a dimpling effect of the skin over the plantar keratosis. If the patient has undergone previous therapy, the keratosis is then excised by means of an elliptical incision. If the keratosis has not been previously treated by fulguration or by irradiation, excision is not necessary. Skin closure has not been found difficult since only the keratosis is excised. The soft tissues on the dorsum of the foot are then closed in the usual anatomical manner, the skin being closed with dermalon sutures. Forty of these procedures have been performed on thirty-one patients.

Immediate Postoperative Care

Following closure of the incision, a snug-fitting, padded plaster cast is applied with the metatarsophalangeal joints held in a position of moderate plantar flexion. The cast is fitted snugly in order that the head of the osteotomized metatarsal may be placed in a slightly dorsal position. A walking heel is applied and the patient becomes ambulatory, with or without crutches, on the fifth postoperative day. The cast is removed at the end

of four weeks. A comma-shaped metatarsal pad, three-eighths of an inch thick, is fitted into the shoe as soon after removal of the cast as the patient can wear it in comfort. This is discarded after six months.

END-RESULT STUDY

Of the forty procedures, the results were *excellent* in thirty-three, or 82.5 per cent. In four, or 10 per cent, the results were considered *good* in that although the initial procedure was successful, a plantar keratosis developed under an adjoining metatarsal head. In the four patients in whom a plantar keratosis developed under an adjoining metatarsal head, no definite pattern of development of the second keratosis appeared to evolve. G.E. initially had a plantar keratosis under the left second metatarsal head. Within one year following surgery, a plantar keratosis developed under the left third metatarsal. However, with a metatarsal pad worn in her household shoes, her foot is comfortable.

H.F. also had a plantar keratosis under the left second metatarsal head. Nine months after shortening of the metatarsal, a plantar keratosis under the third metatarsal head appeared. In this instance, although she first planned to have the third metatarsal shortened, she changed her mind since the discomfort is slight even when she wears high-heeled shoes. Moreover, she recently completed a three months' trip throughout the western national parks without any particular discomfort.

S.C.R. underwent shortening of the second metatarsal of both feet. Within eight to ten months a plantar keratosis developed under the third metatarsal head on the left foot but not on the right. The left third metatarsal was shortened with a subsequent excellent result. The fourth patient initially had a plantar keratosis under the left third metatarsal head. Following surgical shortening a plantar keratosis developed under the second metatarsal head. She has since undergone shortening of the second metatarsal shaft and is now quite happy with the end result.

The author is unable to explain the cause of the second keratosis. If it had occurred under the adjoining lateral metatarsal in each instance, then one could hazard the theory that the shift in the weight-bearing stance, with additional strain on the lateral metatarsal head, was the cause of this complication, but such is not the case. Furthermore, a careful re-evaluation of the feet and of the roentgenograms did not shed any additional light. The metatarsal shortening was neither inadequate nor more than the recommended one-half inch. To confuse the situation further, in the case of S.C.R., both second metatarsal shafts were shortened and another keratosis developed only under the left third metatarsal head. Possibly, as more patients are studied and this complication occurs, as it is bound to, an answer may be found. At present, however, the author cannot suggest any definite cause for this complication or any regimen to prevent it.

In this series, there were three failures (7.5 per cent). An analysis of them reveals that in two patients the shortening was insufficient but both state that the pain is not as intense as it was preoperatively. The third failure was in a patient who had a plantar keratosis under the medial sesamoid bone and excision of the sesamoid bone was performed. The author, at present, is undecided whether removal of one sesamoid bone alone is the procedure of choice. Possibly shortening the first metatarsal shaft in a plantar-angulated position would be the ideal procedure but it has not been attempted as yet.

Of these patients, twenty-four were women and six were men. It is, therefore, evident that fashion definitely contributes to the development of this lesion. The six men had occupations which required excessive standing or use of their feet.

It is interesting to note that the plantar keratosis occurred under the second metatarsal head in eighteen instances, under the third metatarsal head in sixteen, under the fourth in two, under the fifth in one, and under the medial sesamoid bone in three in this consecutive series of thirty-one patients. The cause and effect of this predominance merits further study.

The appearance of a shortened metatarsal six months postoperatively is shown in Figure 5. Preoperative photographs of the lesions and photographs of the same feet three to twenty months following surgery are shown in Figures 6-A through 9-B.

DISCUSSION

The plantar keratosis is nothing more than a reaction of the soft tissue to overlying and underlying abnormal pressures caused, in the author's opinion, by improperly fitted shoes. If this lesion were on the dorsum of the foot or on the toes, it would be called a clavus and comfort would be more easily maintained. Since, however, it is on a weight-bearing surface upon which with each step the entire weight of the body is transmitted, it is compressed into the tissues and becomes disabling. As with the clavus, if the pressure is relieved, the lesion disappears spontaneously. Therefore, conservative therapy for a period at least of six months should be attempted. This was done in this series with each patient who had had no previous therapy. The regimen consisted in the wearing of a comma-shaped metatarsal pad in a properly fitted shoe. This, of course, was very difficult to carry out with the female patients. Although they were willing to wear broad-toed, flat-heeled shoes at home, they refused to do so on all other occasions. In addition to wearing the pad, the patient was advised to trim the keratosis at least once weekly. If the patient failed to experience complete relief with this treatment, surgery was then recommended.

This operative procedure certainly has merit and it has given very satisfactory results in those instances in which the plantar keratosis was found to underlie a metatarsal head or a metatarsophalangeal joint. It is true that it is not always successful. On the other hand, a failure rate of only 7.5 per cent, the failures being primarily caused by errors in technique and judgment, certainly indicates the value of the procedure and proves that the lesion is a pressure phenomenon.

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Clinicopathological Study of Ninety-Four Limbs Amputated for Occlusive Vascular Disease

BY PATRICK J. KELLY, M.D., DAVID C. DAHLIN, M.D., AND JOSEPH M. JANES, M.D.,
ROCHESTER, MINNESOTA

*From the Sections of Orthopaedic Surgery and of Surgical Pathology, Mayo Clinic and Mayo Foundation *, Rochester*

Two of us presented the results of a clinical study of 323 amputations with reference to all factors that determine the site of amputation in occlusive vascular disease [5]. A part of this study included an anatomicopathological study of ninety-four consecutive unselected lower limbs amputated for occlusive vascular disease.

The purpose of the present communication is to record our findings in these ninety-four limbs, in the hope that certain observations can be made that will be of aid in selecting the site of amputation. Many studies have reviewed the pathological changes in the vessels of limbs amputated for occlusive vascular disease [2, 3, 4, 6, 8, 9]. Rodda discussed the examination for arteriosclerosis of the lower limbs of fifty unselected cadavera in the later age groups. However, none of these studies attempted to correlate the pathological changes with the clinical findings that determine the level of amputation.

METHOD OF STUDY

The amputations were performed at the Mayo Clinic between March 1949 and April 1951. Forty of the limbs were amputated through the thigh and fifty-four below the knee. These ninety-four extremities were dissected and the vascular pathological changes were recorded on a sketch of the main arteries of the limb. The vessels studied included the anterior tibial, posterior tibial, and peroneal arteries, as well as the distal portions of the femoral and the popliteal arteries when they were available. The vessels were carefully examined grossly by making cross sections every few millimeters. Multiple fresh frozen sections were prepared and examined microscopically. After representative sections were selected in this manner, fixed sections were made and stained with hematoxylin and eosin and by an elastic-tissue stain, counterstained with van Gieson's solution.

The clinical data on all the patients who had such amputations were available since a comprehensive study of that material had already been made [5].

RESULTS

Thigh Amputations

The forty limbs were divided into four groups on the basis of the pattern of the occlusive lesions in the arteries and on the behavior of the patients' limbs before and after operation.

Group 1 (fourteen limbs): Pathologically, the arteries all showed atherosclerosis obliterans. The tibial and peroneal arteries showed a distinct tendency to segmental involvement. When complete occlusion was present, the lesions were easily distinguished atheromata with superimposed thrombi. These thrombi were fibrous owing to organization; in no case was a fresh thrombus noted at these sites. Between foci of complete occlusion were zones of minimal atherosclerosis.

The typical change in this group was noted in the distal portion of the femoral artery and in the popliteal artery, where fresh thrombi were superimposed on atherosclerotic

* The Mayo Foundation, Rochester, Minnesota, is a part of the Graduate School of the University of Minnesota.

plaques (Fig. 1-A). (The importance of occlusion occurring in this region, namely the area of the adductor canal and the popliteal artery, has been emphasized as a cause of claudication by Boyd and associates.)

Clinically, the patients in Group 1 had extremely ischaemic lower limbs. None of the patients had associated diabetes mellitus. Their records revealed well documented episodes of sudden arterial occlusion occurring within six weeks prior to amputation. Amputation above the knee was performed on these patients purely on the basis of the severe ischaemia.

Group 2 (twelve limbs): Pathologically, the arteries of these limbs showed atherosclerosis obliterans with a distribution of the lesions almost identical with that in Group 1. The only significant difference was the character of the thrombi in the distal portion of the

FIG. 1-A

FIG. 1-B

Fig. 1-A: Fresh thrombus superimposed on atheromatous changes in the popliteal artery. This type of occlusion was noted in the distal portion of the femoral or in the popliteal arteries of all limbs in Group 1 (hematoxylin and eosin; × 15).

Fig. 1-B: Well organized old thrombus in the popliteal artery. This type of thrombus was typical of the occlusive lesion in the distal portion of the femoral or in the popliteal arteries of all limbs in Group 2 (hematoxylin and eosin; × 8).

femoral and in the popliteal arteries. The thrombi in this group were made up of well organized fibrous tissue (Fig. 1-B) in contrast to the fresh thrombi at these levels in Group 1. These thrombi were distinctly different from the fresh thrombus in Figure 1-A, which was made up of delicate strands of fibrin in which erythrocytes were trapped in an occluding mass.

Clinically, diabetes mellitus was present in five of the twelve patients in Group 2. None of these patients had experienced sudden arterial occlusion immediately prior to amputation. Rather, the ischaemic lesion necessitating amputation usually was precipitated by some form of trauma to an already ischaemic limb. While ischaemia was pronounced in this group, it was not so severe as that in Group 1. The decision to amputate above the knee often was determined by factors other than ischaemia alone.

Group 3 (eight limbs): Pathologically, the usual segmentally occluding atheromata and thrombi were noted in the anterior tibial, posterior tibial, and peroneal arteries of this

group, as they were in the previous two groups. The popliteal and femoral arteries were affected by atherosclerosis but they were not occluded by thrombi, either old or fresh.

Clinically, diabetes mellitus was present in six of these eight patients. Of all limbs amputated above the knee, this group of extremities had the least amount of ischaemia. Thus, the decision to amputate above the knee often was determined by factors other than ischaemia, such as a poorly functioning knee joint, the slim possibility of rehabilitation even if amputation were below the knee, or because the general health of the patient militated against more than one operation.

Group 4 (six limbs): Pathologically, this group was heterogeneous. Four limbs exhibited embolism at the proximal end of the popliteal artery. One limb had an atherosclerotic aneurysm of the popliteal artery, with a fresh thrombus occluding the channel of the aneurysm. The remaining specimen revealed segmental atheromatous changes, with superimposed thrombosis of the femoral and popliteal arteries and minimal atherosclerotic changes in the anterior tibial, posterior tibial, and peroneal arteries. This unusual distribution of atherosclerosis was not present in any other limb in our entire series.

Clinically, these patients all had histories of recent sudden arterial occlusion, extensive gangrene, and severe ischaemia, all of which made it compulsory to amputate above the knee. These patients were similar to those in Group 1 in that fresh thrombi were present in the femoral or the popliteal arteries or in both, secondary either to emboli or to atherosclerosis. The history of recent sudden arterial occlusion, the severe ischaemia, and the fact that none of the patients had diabetes mellitus made Groups 1 and 4 quite similar.

Below-the-Knee Amputations

A total of fifty-four extremities amputated below the knee were studied; thirty-nine had atherosclerosis obliterans, eleven had thromboangiitis obliterans, two had embolism, and two had popliteal aneurysms of atherosclerotic origin. Severe limitation in the observations regarding the vascular tree is imposed by having only the tibial arteries and the peroneal artery available for study. From the preceding discussion of amputation through the thigh, it is apparent that many of the important occlusive lesions are in the popliteal and femoral arteries.

As already noted, a repetitious pattern of segmental occluding lesions was present in the tibial and peroneal arteries of limbs affected by atherosclerosis obliterans. The same pattern of atheroma or atheroma and thrombi was present in limbs amputated below the knee for atherosclerosis. The thrombi in all but two of these arteries were old and well organized. These fresh thrombi, which were in the superior portions of the tibial arteries, could well have been extensions of fresh thrombi in the popliteal artery. Both these patients had serious wound complications, and their histories indicated sudden arterial occlusion in the popliteal region shortly before amputation.

Typical arterial lesions were noted in the eleven specimens with thromboangiitis obliterans (Fig. 2-A). The arterial lumina were filled with thrombi that were well organized and cellular. These thrombi were canalized by thin-walled vessels. The internal elastic lamina was intact, while the tunica adventitia was thickened by increased fibrous tissue. The artery and the accompanying veins and nerves often were bound together by this perivascular fibrosis, but this pathological finding was not vital to the diagnosis. When such changes were associated with a typical clinical history, the diagnosis was not difficult.

COMMENT

The occurrence of fresh thrombi in only two of the limbs amputated below the knee for atherosclerosis contrasts with the findings of Wessler and Schlesinger, who noted fresh thrombi in half of the amputated limbs that they reviewed. The presence of fresh thrombi in the superior portions of the tibial arteries in these two cases may be a significant observation, since both of those patients had serious wound complications.

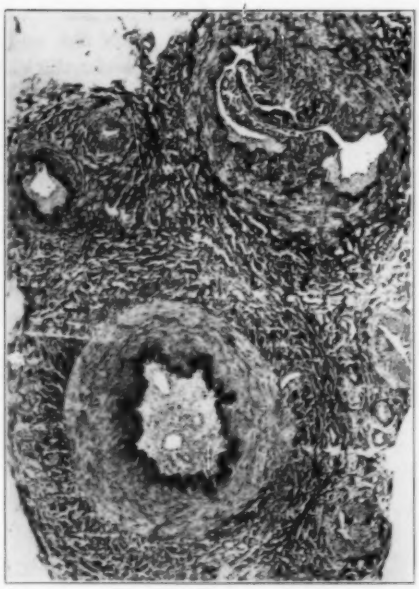

FIG. 2-A

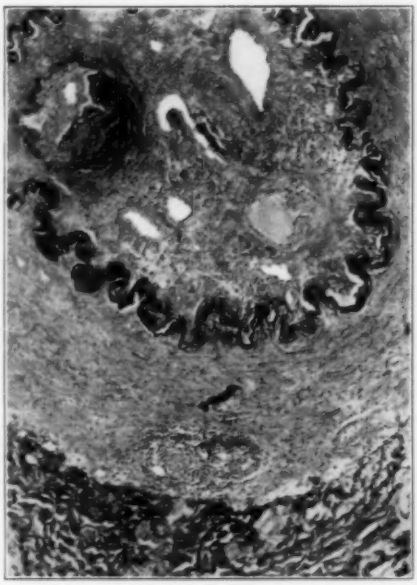

FIG. 2-B

Figs. 2-A through 2-D: Sections stained by elastic tissue, counterstained with van Gieson's solution.
Fig. 2-A: Typical arterial and periarterial lesion of thromboangiitis obliterans. Note the vascular organized thrombus occluding the lumen (× 30).
Fig. 2-B: Ancient thromboangiitis obliterans in the posterior tibial artery. A small granuloma can be seen in the tunica media (× 55).

FIG. 2-C

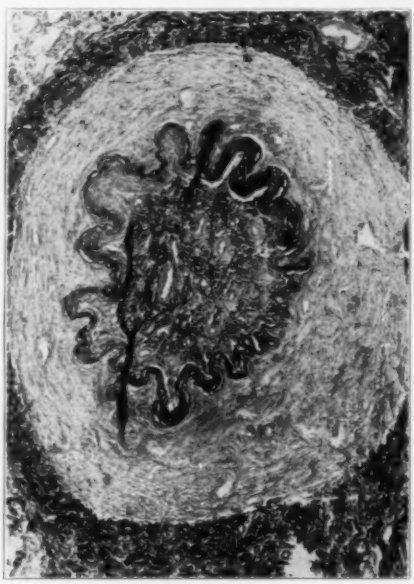

FIG. 2-D

Fig. 2-C: Popliteal artery from same limb as seen in Fig. 2-B. Note atheroma and ancient thrombus (× 20).
Fig. 2-D: Old organized thrombus in the anterior tibial artery secondary to distal embolization of a femoral aneurysm (× 40).

Only one of the eleven patients with thromboangiitis obliterans in our series subsequently required amputation above the knee. This man, fifty-seven years old, had a twenty-year history indicative of thromboangiitis obliterans. Amputation below the knee finally was resorted to because conservative measures had failed. The posterior tibial artery showed changes consistent with thromboangiitis obliterans (Fig. 2-B). The site of amputation failed to heal and re-amputation above the knee was necessary. The popliteal artery revealed typical atheromata and thrombi (Fig. 2-C). While this situation is uncommon, the improved conservative management of thromboangiitis obliterans may allow a number of patients who have this disease at a relatively early age to live long enough to become subject to atherosclerosis obliterans at a later age.

Goodman and associates described a pathological entity of the anterior and posterior tibial and peroneal arteries that they called "arteriofibrosis obliterans." They did not note atheroma in any of these arteries and, since three of the five limbs they examined were from diabetic patients, they apparently indicated that this was a specific change in diabetics who had occlusive vascular disease. We carefully reviewed the thirty limbs from diabetics included in our total of ninety-four extremities; nineteen of these limbs had been amputated below the knee and eleven above the knee. We were unable to find any occlusive vascular lesion that was specific for diabetes. We were able to distinguish atheromata with associated well organized thrombi, as have been described previously by Hines and Barker.

The pathological features of thromboangiitis obliterans can be confused with those of other forms of occlusive vascular disease, such as thrombosis secondary to embolism. It is important to distinguish these entities because thromboangiitis obliterans can be treated by conservative amputation, if amputation is necessary, whereas embolism, when it causes an ischaemic lesion necessitating amputation, almost invariably requires amputation above the knee. Figure 2-D shows a section of the anterior tibial artery that superficially resembles the picture of thromboangiitis obliterans. This patient had an aneurysm of the femoral artery; close inspection of the vessel revealed the lack of cellularity of the thrombus and the relatively normal tunica adventitia. Figures 3-A and 3-B show sections of the anterior and posterior tibial arteries that also resemble the picture of thromboangiitis obliterans at first glance. However, this lesion is a thrombus secondary to embolism of the popliteal artery. The lack of cellularity of the thrombus and the relatively normal tunica adventitia help to distinguish this from thromboangiitis obliterans.

We consider that this pathological study, when correlated with the previous clinical study of the same material [5], allows certain conclusions to be drawn. Both the clinical and the pathological studies indicate that the patient who has atherosclerosis and associated diabetes does not often have sudden arterial occlusion precipitating a lesion which requires amputation of the limb. Secondly, occlusive vascular disease in diabetic patients shows no fundamental difference in its pathological changes, grossly or microscopically, from atherosclerosis obliterans. We could recognize no arterial lesion that is specific for diabetes. It is well known that the diabetic is especially subject to infection and neurotrophic lesions of the foot that further confuse the picture. Adequate evaluation of these accompanying factors is essential to the understanding of the vascular lesions in diabetics with atherosclerosis.

A considerable amount of vascular occlusion can be present in the tibial and peroneal arteries before an irreversible ischaemic lesion appears. Our study indicates that a thrombus of the femoral artery in the adductor canal or of the popliteal artery produces the most profound ischaemia, especially if it is recent in onset. This fact, together with the general segmental character of atherosclerosis obliterans, tends to stimulate us to the use of surgical methods, such as arterial bypass, that promote increased vascularity to the limb.

Accurate evaluation of the pathological changes in the arteries of any limb amputated for occlusive vascular disease is necessary. It is important to study all cases in which

typical lesions of atherosclerosis obliterans or thromboangiitis obliterans are absent. Less common causes of occlusive vascular disease, such as peripheral aneurysms and embolism, occur and require special consideration.

We were unable to demonstrate a quantitative difference in the degree of occlusion in the tibial and peroneal arteries of limbs amputated above or below the knee. This points out even more conclusively the important changes that occur in the distal portion of the femoral and in the popliteal arteries. We recognize, of course, that occlusive lesions occur in the distal part of the aorta and in the iliac vessels, but their consideration is beyond the scope of this paper.

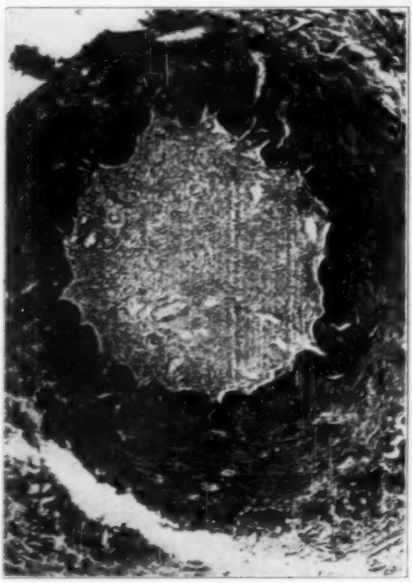

FIG. 3-A

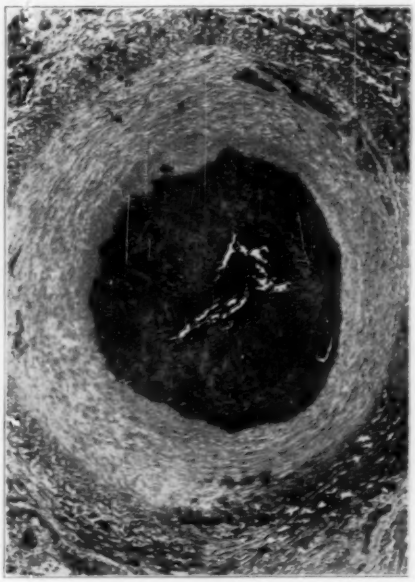

FIG. 3-B

Figs. 3-A and 3-B: Thrombus in the tibial arteries secondary to embolism of the popliteal artery.
Fig. 3-A: Anterior tibial artery (elastic-van Gieson; × 50).
Fig. 3-B: Posterior tibial artery (hematoxylin and eosin; × 35).

SUMMARY AND CONCLUSIONS

A clinicopathological study was made in ninety-four cases in which extremities were amputated at the Mayo Clinic for occlusive vascular disease; forty amputations were through the thigh and fifty-four were below the knee.

Dissection and microscopic examination of the forty limbs amputated above the knee demonstrated the segmental nature of the occlusive arterial lesions in atherosclerosis obliterans. Limbs amputated above the knee that contained fresh thrombi in the femoral or popliteal arteries were clinically the most ischaemic of the entire series of ninety-four limbs examined.

Patients with diabetes mellitus who were subjected to amputation above the knee did not have fresh thrombi in the popliteal or femoral arteries. This correlates with the clinical finding that recent sudden arterial occlusion is relatively infrequent as the initiating factor for amputation in patients with both atherosclerosis and diabetes.

The anterior tibial, posterior tibial, and peroneal arteries of limbs amputated for atherosclerosis obliterans showed no quantitative differences in the degree of occlusion in those amputated above the knee compared with those amputated below the knee.

The old lesions of thromboangiitis obliterans may bear a strong histological resemblance to certain other thrombotic lesions, such as those secondary to emboli. The microscopic picture of thromboangiitis obliterans is not always specific and its diagnosis requires that the pathologist be familiar with the clinical history and findings in all cases.

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Open Grafting of Raw Surfaces of the Hand*

BY BRADFORD CANNON, M.D., BOSTON, MASSACHUSETTS

From the Departments of Surgery, Harvard Medical School, and Massachusetts General Hospital, Boston

There is universal agreement that the burned hand should be promptly covered by skin grafts following early surgical excision of all non-viable skin and underlying tissues or following spontaneous separation of these tissues. Following surgery, complete and permanent skin coverage may be expected by means of thorough débridement and primary grafting. However, after spontaneous separation, grafting may have to be delayed because of the presence of open joints or exposed bone and tendons. The granulation tissue in such deeply burned hands often remains oedematous and the exudate profuse, despite local clean care and the parenteral administration of antibacterial agents. The technique of open skin-grafting has been applied successfully to these different types of injured hands which present reparative surgical problems and in which conventional methods either failed or appeared unsuitable.

Surgeons have long noted a prompt spontaneous and firm adhesion between a split-skin graft and a healthy granulating surface. This unexplained adhesion between the tissues is thought to result from the formation of a fibrin network which seals the graft in place [4]. A number of methods of enhancing the adhesion have been suggested in the past, including the coagulum contact method of Sano; chick-embryo extract, chicken plasma, thrombo-plastin [1]; fibrinogen and plasma-thrombin fixation [7]. Each of these methods for promoting the adhesion of the graft was used by Brown but in no instance was there any increase in the survival of the graft over that of the untreated control graft observed. It must be concluded from this observation that there are normally present on the surfaces of the skin graft and the well prepared wound all the substances necessary for adhesion of the graft to the granulating surface.

Studies [2] have been carried out recently at the Massachusetts General Hospital on the influence of temperature and humidity in the healing of the normal donor area. The observations described there emphasize the value of maintaining normal skin temperature and avoiding excessive moisture at the healing surface. The skin temperature of the donor area covered by a dressing was consistently 2 to 4 degrees Fahrenheit higher than the uncovered donor site. Both areas, traumatized by the taking of a graft, were as high as 10 to 12 degrees Fahrenheit warmer than the uninjured control skin. The dressing covering a donor area decreases surface evaporation so that moisture may persist in the dressing and the wound; it was observed for as long as ten days or more after operation. This is in contrast to the exposed donor area, which is dry. Healing of the uncovered donor area was not accelerated by exposure but there were delays in healing of the covered areas when the dressing remained wet. However, spontaneous and qualitatively normal healing occurred after the outer dressing was removed. The layer or two of gauze, which must be left undisturbed on the donor area, dried rapidly, and in a few days could be separated from the healed surface. The temperature of the skin beneath the dry gauze promptly fell approximately to that of the exposed donor site.

Survival of a skin graft on a granulating surface depends on rapid establishment of new circulation. Failure usually resulted from autolysis within the graft or suppuration without, due occasionally to technical errors which permit graft disintegration, or to separation of the graft from its new bed by pus. Most bacteria which are pathogenic for

* Read at the Annual Meeting of the American Society for Surgery of the Hand, Chicago, Illinois, January 26, 1957.

FIG. 1-A

FIG. 1-B

FIG. 1-C

Figs. 1-A, 1-B, and 1-C: Photographs showing deep flash burn of the hand with permanent damage and ultimate fusion of several interphalangeal joints.

Fig. 1-A: Photograph showing clean but persistently oedematous granulation tissue, particularly in the region of the open joints.

Fig. 1-B: Appearance of the hand at operation with all raw surfaces covered by split-skin grafts and protected by a wire cradle incorporated in a forearm plaster splint.

Fig. 1-C: Photograph made after ten days shows that the hand is almost healed and active joint motion has begun.

man grow at the optimum temperature of about 98.6 degrees Fahrenheit [5]. Chilling the bacteria will depress their growth, a method applied clinically to the seriously infected extremity prior to amputation. There are disadvantages in cooling, however, since a lag in wound healing has been observed following twenty-four to forty-eight hours' chilling to 42 degrees Fahrenheit [5]. Bacterial growth also is inhibited by drying, and complete desiccation will destroy most pathogenic organisms. Thus the successful healing of a skin graft may be influenced by environmental temperature and humidity.

It was found that the surface temperature of an exposed skin graft approaches that of the normal adjacent skin within a few days after its transfer. Simultaneous temperature readings showed that a graft protected by a dressing averaged 4 degrees Fahrenheit higher than the normal adjacent skin. A covered graft on the trunk had temperatures within 1 to 2 degrees Fahrenheit of the body temperature.

On the basis of these observations the technique of open grafting in the covering of granulating wounds has been used with increasing frequency.

FIG. 2-A

FIG. 2-B

Figs. 2-A, 2-B, and 2-C: Photographs showing deep electrical burn of thumb exposing cortical bone and interphalangeal joint.

Fig. 2-A: Oedematous granulating wound surface following débridement is shown in photograph.

Fig. 2-B: Photograph of hand shows graft in place, perforated at site of exposed bone, and protected by wire cradle incorporated in dressing.

Fig. 2-C: Photograph of healed wound showing collapse of thumb and contraction of graft due to absence of bone support.

FIG. 2-C

INDICATIONS

It must be emphasized that this method has only limited indications. There is still no better method for the protection of a graft on a well prepared surface than an accurately applied dressing. Only when there are technical problems of effective immobilization of the graft or when the condition of the granulating wound is uncertain will the open-grafting technique offer an alternative method that may prove simpler, more effective, and less hazardous in securing closure. In areas which cannot be immobilized, such as the thoracic or abdominal walls, a dressing acts as a relatively inflexible object dislodging the graft rather than protecting it. Undesirable delays in early grafting of the severely injured or deeply burned hand may permit serious crippling of the moving parts of the fingers, ankylosis of joints, and fixation of tendons. These delays are usually due to persistent oedema of the granulation tissue of the wound. The oedema of this tissue is related to exposed or infected bone, tendon, or joints. When these deep structures are exposed and infected the firm granulation tissue which is ideal for grafting will not develop, and consequently delays in grafting may be necessary. By use of the open method without dressings early skin-grafting may be possible despite persistent oedema in the wound. If the grafting is limited to the granulation tissue and none is applied over the areas of active infection, a take is usually possible. Absolute splinting of the hand is also unnecessary. Bone cavities resulting from saucerization, in which bone of doubtful viability may remain, can be lined with skin grafts. Spontaneous covering of the exposed bone has been observed in a number of instances. Even spinal-fluid fistulae in the back have closed spontaneously when the surrounding granulating wound was converted to a healed wound with a skin graft. In persons with paraplegia most skin-grafting can be done by the open method because practically all motions

FIG. 3-A

FIG. 3-B

Figs. 3-A and 3-B: Photographs showing bone defect in tibia, which, following saucerization for osteomyelitis, was closed successfully a few days later with skin grafts. Grafts were protected by single layer of gauze anchored with collodion.

of the lower trunk and lower extremities are performed by the attendants, who will avoid dislodging the graft.

PREPARATION OF THE WOUND

When the method of open grafting is used, survival of the graft can be anticipated on oedematous granulations or on surfaces which are not as surgically well prepared as is desirable. This does not mean that the wound can be neglected or that the thorough, meticulous treatment required for the management of an open wound can be disregarded. The method does, however, permit earlier grafting in areas where necrotic tissue is present but not yet sequestered, or where non-viable tendon, open joints, or exposed bone are still present in the wound.

Daily changes of dressing are necessary before grafting is contemplated, and twice-daily dressings may be better if the amount of exudate is large. These are desirable with a single layer of fine gauze in firm contact with all parts of the raw surface and covered by a protective dressing. Usually, when the dressing is applied it is moistened with an isotonic solution to accelerate absorption from the wound, just as one must moisten a kitchen sponge before it will absorb water. It is not wise to keep the dressing wet constantly unless there is evidence of invasive infection. Slow drying during the period of contact of the dressing with the wound is desirable.

Gentle débridement, sponging away of any exudate, removal of marginal crusts, and thorough cleansing of the surrounding skin are all essential factors in proper wound care prior to grafting.

THE GRAFT

The thick graft, usually secured with a dermatome, is unsatisfactory when the open method is used. The elasticity of the graft complicates fixation and its thickness increases the risk of destruction before adequate vascularization is established. It is preferable either to remove a thinner graft with a knife or its equivalent or to use an inelastic backing for the graft to prevent shrinkage. After it is cut, the graft need merely be set aside in a moist sponge. There is never any indication to open out the graft on a flat surface, wash it with saline, or manipulate it in any other way.

TRANSFER OF THE GRAFT

The granulating surface to which the graft is applied need not be prepared by any sterilizing agent if the dressing removed in the operating room were applied within the previous twelve to eighteen hours. Washing of the graft or the granulating surface delays the development of an adhesion between them, presumably because of the removal of

tissue substances important for the development of the adhesion. Also, if the granulations are disturbed, there is likelihood of starting surface bleeding.

SPLINTING

Absolute splinting of the part grafted is not necessary. A minimum of motion of the fingers, for example, or the respiratory motions of the trunk are well tolerated by the adherent graft. The greatest danger is contact with bedding and inflexible objects. It was found desirable to construct a cradle about the grafted area over which a layer of gauze could be draped. This served as a protection against contact with bedding or other objects and minimized external contamination of the wound. A cradle about the hand, fixed to a forearm plastic splint, may be suspended to an overhead frame for support and additional protection. The extension of a plaster slab into the palm will support the wrist or fingers in a position of function and yet permit limited motion of the parts.

POSTOPERATIVE CARE

Revascularization of the graft takes place rapidly. By the end of forty-eight hours, it becomes pink. According to Converse and Rapaport, blood cells can be seen with a stereomicroscope circulating in the vessels of the graft by the third or fourth day. By this time the skin has become red and free bleeding both from the graft and the raw surface is observed if the margins of the graft are accidentally elevated. Gentle daily removal of all exudate and crusts between the edges of the graft and the adjacent normal skin or adjacent graft should begin by the second or third day to avoid concealed infection that can undermine and destroy the viable graft. By the seventh or eighth day the grafts are usually stabilized and a return to daily wet dressings will usually simplify wound care and hasten final healing.

SUMMARY

There is increasing evidence that the environmental temperature and humidity about a skin graft may influence its survival. There is also evidence that adhesion between a skin graft and a clean granulating surface occurs almost the moment that the graft is applied. This has led to a decrease in the use of dressings for compressing and immobilizing skin grafts applied to granulating surfaces. The temperature of the graft approximates more closely the normal temperature of the skin, and the wound is kept dryer by evaporation. Limited motion of underlying parts such as the fingers or the abdominal or chest walls will not cause displacement of the adherent grafts. The grafts will move with the underlying tissues.

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DISCUSSION

Dr. W. Brandon Macomber, Albany, New York: Our Clinic has adhered to the closed method in grafting. We feel that the dressing of a graft offers certain advantages:

1. The painful hand will usually assume a position of malfunction. The proper dressing will maintain this hand in the desired position of function while the grafts are taking and being stabilized.

2. A greater success of takes in our hands has been made possible by having a bed completely free of granulations. Granulations are infected, they form scar beneath the grafts causing a contracture of the skin and in many cases necessitate further definitive surgery. This technique of avulsing granulations [a] has been most successful in our hands.

3. This technique definitely demands a pressure dressing so that oozing will not float the graft from its bed.

4. Any secretions from an open wound may form an eschar and seal off drainage that will elevate the graft. A xeroform pressure dressing with moist saline compresses will absorb secretions through a perforated graft.

5. Of course, motion of a part will disturb the graft. A pressure dressing with the hand in the position of function will prevent this possibility.

6. With evaporation of the moist dressing, the recipient site is cooled, so that temperature has not been a factor in our hands.

a. Macomber, W. B., and Patton, H. S.: Improved Grafting Technic for Burns of the Extremity. Am. J. Surg., **73:** 684-689, 1947.

Dr. Walter C. Graham, Santa Barbara, California: I feel that the thing we are not stressing sufficiently today is the fact that a thin graft is one which we can use to close a wound. If definitive surgery is going to be necessary we must have sufficient soft tissue, and if the thin graft does not afford this a later flap operation may be necessary, replacing the previous thin graft. If one can get rid of the granulating tissue by closing the wound with skin graft, it will prevent the development of scar tissue. Dr. Cannon mentions the loss of tendons. We all know that we will lose tendons, and also have involvement of the joints in severe burns, particularly on the dorsum of the hand. Such a situation causes a great deal of trouble, and even a flap does not give an opportunity to make a new useful finger, if the tendons are gone, and we will end up with a contracted and shiny finger, sensitive on its dorsal aspect. Another point, also, is that we do not know how deeply the tissue is burned. If there is loss of bone tissue it is important to maintain the length of the digit to later facilitate better function. Often a thin graft will be sufficient, but a permanent graft should be much thicker, as it will not contract. This is particularly true when a large area is being covered.

Dr. Robert M. McCormack, Rochester, New York: In the early forties, Young did some work on plasma-thrombin fixation of skin grafts. Clinically, it did not make much difference which method of fixation was used to promote adhesion of the graft.

We, too, have been impressed with the procedure of exposing the donor sites. We have used no dressing whatsoever on the donor sites. A bloody scab gradually forms which will come off the new epithelium in about three weeks. In the experimental laboratory in pigs we merely tack the graft at the corners, apply no dressing, and have got quite excellent takes. In the patient, one must be a bit more careful with the open method of skin-grafting. When human skin-tissue cultures are exposed to the air for fifteen to twenty minutes, one will see death of the cells from dryness. This fact is well known in various tissue and bacterial cultures. When one is exposing a skin graft, one must be careful of excessive dryness. I would suggest that the graft be examined frequently in the first forty-eight hours. If evidence of dryness appears, the graft should be moistened with a sterile physiological solution.

Dr. Cannon (closing): I want to emphasize that this method is not universally applicable. It is merely cited as one which is available and useful in circumstances when conventional methods of grafting are not feasible. Nevertheless, this method is an effective way of closing a wound.

Sensory Disturbances in the Hands of Children with Cerebral Palsy

BY MIHRAN O. TACHDJIAN, M.D., CHICAGO, ILLINOIS
AND WILLIAM L. MINEAR, M.D., PH.D., ALBUQUERQUE, NEW MEXICO

The purpose of this paper is to report the results of the sensory examination of the hands of ninety-six children with cerebral palsy.

Tizard and associates and Hohman and associates have reported their studies on sensory disturbances in cerebral palsy.

MATERIAL AND METHODS

During the years 1945 to 1955 inclusive, 800 children with cerebral palsy were seen at the Carrie Tingley Hospital for Crippled Children, Truth or Consequences, New Mexico. Of these, ninety-six patients were chosen for this study.

Intelligence Level, Age, and Sex

A sensory examination is influenced by many subjective factors. To make the report dependable, all the children studied had an average or a normal intelligence level, determined mainly by psychological evaluation. The average age was ten years, the minimum being six and the maximum being nineteen years. Forty of the patients were females and fifty-six were males.

Type of Cerebral Palsy

The incidence of the various types of cerebral palsy in the patients examined is shown in Table I. Most of the patients (67 per cent) had spastic hemiplegia. In the spastic quadriplegic patients, the spasticity was more marked on one side. We especially chose such patients in order to have the contralateral extremity serve as a control.

Modalities Tested and the Method of Examination

A total of thirteen modalities were tested. Each stimulus was repeated five times, with the child's eyes blindfolded by an assistant. All the children were very cooperative, and enjoyed the examination as a game.

1. *Stereognosis:* To be certain the patient could recognize each of the objects, they were first shown to him. Then, with the patient blindfolded, they were placed in his normal hand (or less involved hand in the quadriplegic patients), and finally in his involved hand. The patients were asked to identify the following objects: a button, a key, a safety-pin, marbles, a pen, and wooden articles of different shapes—blocks, triangles, circles, and ovals.

2. *Position sense:* The patient was asked to identify the position of his finger as it was moved up or down.

3. *Two-point discrimination:* Lead-point calipers were used to determine the smallest area in which two touch points could be separately perceived. This was compared with two-point discrimination in the normal hand.

4. *Number writing:* Numbers were traced lightly on the skin and the patient was asked to identify them.

5. *Weighing perception:* Wooden blocks of the same dimensions were filled with different amounts of shot and thus weighed one, two, four, and eight ounces.

6. *Vibration sense* was tested with a tuning fork placed over each metacarpal head.

The following modalities were tested in the conventional manner:

Texture, rough and smooth; dry and wet; localization of tactile stimuli; hot and cold; sharpness and dullness; light touch; and length measurement.

Muscle Tests

Muscle tests of the upper extremities were performed on most children.

Length and Girth of the Upper Extremity

1. Circumferences of the arms and forearms were measured at identical levels.

2. The lengths of the normal and involved upper extremities were measured from the tip of the acromion to the tip of the olecranon with the elbow flexed at 90 degrees, and from the tip of the olecranon to the tip of the middle finger with the forearm, wrist,

TABLE I

INCIDENCE OF THE TYPES OF CEREBRAL PALSY STUDIED *

Type of Cerebral Palsy	No. of Patients	Per cent
Spastic hemiplegia	64	66.7
Spastic quadriplegia	24	25.0
Athetoid quadriplegia	7	7.3
Athetoid hemiplegia	1	1.0

* Total number of patients is ninety-six.

TABLE II

INCIDENCE OF SENSORY DISORDERS IN CEREBRAL PALSY, AS COMPARED WITH VARIOUS AUTHORS

Author	No. of Patients Examined	No. of Patients with Sensory Defects	Per cent
Tizard and associates	106	57	53.8
Hohman and associates	47	34	72.3
Tachdjian and Minear	96	40	41.7

TABLE III

MODALITIES IMPAIRED AND THEIR INCIDENCE

Type of Sensation Impaired	No. of Patients	Per cent of Total
Stereognosis	40	41.7
Two-point discrimination	31	32.3
Position sense	16	16.6
Number writing	8	8.3
Weighing perception	4	4.2
Localization of tactile stimuli	4	4.2
Sharp and dull discrimination	3	3.1
Hot and cold	1	1.0
Length measurement	1	1.0

and fingers held in a neutral position by an assistant. The accuracy of the above was checked by roentgenographic measurements in a few patients. Errors of one-eighth to one-quarter of an inch were found.

Thermocouple Studies

Thermocouple studies were done by taking bilateral skin temperature readings of

the extensor and flexor surfaces of the arm, forearm, and hand and recording the differences, if any. Meticulous care was exerted to rule out all possible sources of error.

Functional Use of the Involved Hand

Functional use of the involved hand was evaluated and graded as *none*, *poor*, *fair*, *good*, and *normal*, depending on how much the patient used his hand. An end-result determination of the treatment received by these ninety-six patients was made. These examinations were done during a total period of nine months. As the children were seen once every three months in the out-patient clinic of the Carrie Tingley Hospital, all of them had these examinations made on at least two different occasions; 30 per cent of them had these examinations made on three different occasions. The results of each different examination were compared and checked.

TABLE IV

INCIDENCE OF EACH SENSORY DISTURBANCE IN THE VARIOUS TYPES OF CEREBRAL PALSY

Type of Sensation Impaired	Spastic Hemiplegia	Spastic Quadriplegia	Athetoid Hemiplegia	Athetoid Quadriplegia
Stereognosis	30	9	0	1
Two-point discrimination	22	8	0	1
Position sense	10	5	0	1
Number writing	5	3	0	0
Weighing perception	2	2	0	0
Localization of tactile stimuli	2	1	0	1
Sharp and dull discrimination	2	1	0	0
Hot and cold	1	0	0	0
Length measurement	1	0	0	0

RESULTS

Incidence of Sensory Defects

Sensory disorders were found in forty of the ninety-six children (41.7 per cent). Table II compares our incidence with that of various other authors.

Modalities Impaired and Their Incidence

The modalities impaired and their incidence are shown in Table III. Astereognosis, diminished two-point discrimination, and loss of position sense were the most common sensory defects. Those patients who failed to distinguish numbers traced lightly on the skin and who had impaired weighing perception, localization of tactile stimuli, sharp-and-dull discrimination, and temperature and length measurement, also had impairment in one of the three major modalities stereognosis, two-point discrimination, or position sense.

Incidence of Each Sensory Disturbance

The incidence of each sensory disturbance in the various types of cerebral palsy is shown in Table IV.

Correlation of the Underdeveloped Involved Upper Extremity with the Functional Use of the Hand, Muscle Test and Skin Temperature Difference

All of the children with cerebral palsy showed varying amounts of underdevelopment of the involved upper extremities as compared with the normal extremities. The average total shortening of the involved upper extremity was one and three-eighths inches; the minimum being one-half inch and the maximum, three inches. The average atrophy of

the arms was one and three-quarter inches and of the forearms one inch. The extremities which had marked involvement with cerebral zero muscles and which were functionally evaluated as *poor* had the greatest shortening and atrophy. In five patients, there was a constant skin temperature difference—the involved upper extremities were 1 to 2 degrees Fahrenheit colder than the normal or less involved. This difference could not be demonstrated in the remaining ninety-one patients.

Correlation of the Functional Status of the Hand with the Incidence of Sensory Defects

Table V shows the correlation between the functional status of the hand and the incidence of sensory defects. There was a high incidence of sensory defects in functionally disabled hands. Thirty-nine of the forty hands with sensory defects were functionally evaluated as poor, fair, or completely useless. Normal sensation existed in one completely useless and nine functionally poor hands.

TABLE V

FUNCTIONAL STATUS OF THE HAND CORRELATED WITH THE INCIDENCE OF SENSORY DEFECTS

Functional Status of the Hand	No. of Hands	No. of Hands with Sensory Defects	Per cent
None	8	7	87.5
Poor	29	20	68.9
Fair	40	12	30.0
Good	15	1	6.6
Normal	4	0	0.0

DISCUSSION

Cerebral palsy is caused by a non-progressive brain lesion or lesions. It incorporates, to varying degrees, a variety of motor, sensory, and mental difficulties in the individual patient. In the past, emphasis was placed on mental and motor handicaps. Unfortunately, the subject of sensory disorders in cerebral palsy had been ignored until recently when the high incidence was reported by Tizard and associates and Hohman and associates.

Neurophysiological Considerations

A modality is defined as a distinct subjective sensory response to stimulation. Perception is an elaboration of sensation, involving the synthesis of information of several modalities or a temporal pattern of a single modality [1]. Stereognosis, for example, is not a sense; it is a perception based upon the fusion of several modalities—touch and proprioception mainly.

The parietal lobes are the principal somatosensory cortices with the thalamus as their sensory gateway. The postcentral gyrus (areas 3 and 1) is primarily a sensory center, whereas the precentral gyrus (area 4) is primarily motor. Both are closely united by connecting neurons to form a *sensorimotor functional unit* [3]. Stimulation of the postcentral gyrus produces most sensory responses; however, stimulation of the precentral gyrus will also produce some sensory responses. The reverse is true for motor responses.

Permanent sensory defects that are produced by cortical lesions are only those that are discriminative and have a strong spatial element, for example; defects in stereognosis, two-point discrimination, topognosis, and the identification of numbers traced lightly on the skin. Perceptions of temporal pattern (vibratory sensibility) are affected less frequently by cortical lesions unless they extend into the white matter; then, any permanent damage of crude or simple sensations, for example, touch, pain, and temperature, implies a subcortical damage.

The results of this study (in accord with those of Tizard and his associates and Hohman and his associates) disclose that the most common sensory defects are astereognosis, impaired two-point discrimination and position sense. Four of our patients also lost the ability to distinguish weight, eight patients did not recognize numbers traced lightly on the skin, four patients could not localize tactile stimuli, and one patient failed to identify length measurement. These are perceptual functions which are affected by lesions of the somatosensory cortices. The sensation of temperature in one patient was disturbed and in three patients discrimination between sharp and dull was not possible. Lesions of the parietal lobes do not permanently destroy these modalities. Probably these modalities are due to subcortical lesions. None of the patients lost the tactile sense of vibration, wetness, dryness, texture, or light touch. In the hemiplegic patients, the contralateral normal extremities had normal sensation. In the quadriplegic patients, as noted previously, the spasticity or athetosis was more severe on one side. Their less involved sides had normal sensation.

Only one of the eight athetoid patients (12.5 per cent) had sensory disturbances, as compared with thirty-nine of the eighty-eight children with spasticity (44.3 per cent). The number of athetoid patients is statistically too small to enable us to draw definite conclusions regarding the apparently low incidence of sensory disturbances. However, these findings do seem reasonable from a neurological point of view, since the major extrapyramidal structures, the basal ganglia, for example, are well separated from the sensory pathways and areas.

Etiological Considerations

In the pathogenesis of sensory defects in the hands of children with cerebral palsy there are two etiological factors to consider: organic brain lesions in the parietal cortices, the thalamus, or both, and inexperience in using the hand. In some cases the latter might be the major factor. Which plays a greater role in the individual case is hard to determine. The brain damage might be due to birth trauma with hemorrhage and atrophy, primary developmental failure, and other causes. By definition, cerebral palsy is caused by a nonprogressive brain lesion (or lesions), and it is generally accepted that the motor and mental handicaps are due to organic brain lesions. Penfield and Jasper have stressed the close interrelationship of motor and sensory cortices.

Underdevelopment of the Involved Upper Extremity

Disuse atrophy causes underdevelopment of the involved upper extremity. Bilaterally equal skin temperatures in ninety-one of the ninety-six patients probably indicate normal circulation in the upper extremities and speak against decreased blood flow as the cause of the atrophy and shortening; however, the five patients whose involved upper extremities were constantly 1 to 2 degrees Fahrenheit colder than the normal showed the greatest atrophy and shortening.

Practical Significance in Orthopaedics

An end-result determination of the hands of the ninety-six children with cerebral palsy was made. All patients had had extensive physical therapy. Fifteen of those forty patients with sensory defects had had surgical treatment. Multiple operative procedures were done in most of these patients. They consisted of the following:

1. Release of the contracted, spastic muscles and, whenever possible, their transfer to cerebral zero muscles. This was done in fifteen patients. The adductors of the thumb were released in six patients. The insertion of the pronator teres was sectioned and transferred to the extensor carpi radialis longus and the extensor carpi radialis brevis in eight patients. The flexor carpi ulnaris and the flexor carpi radialis were released and trans-

ferred into the extensors of the wrist and into the extensor digitorum communis in seven patients.

2. The wrist was fused in a functional position in two patients.

3. A bone-graft block was made between the first and second metacarpals and the thumb was brought in abduction and optimal opposition in one patient.

The end-result determination was made from one to nine years after surgery, with an average of three and one-half years. As this study was carried on during a period of nine months, the functional rating of these fifteen hands *prior to surgery* was made in retrospect by questioning the parents and the patient and by consulting records. Prior to surgery the fifteen hands were functionally rated as follows: five, *fair;* nine, *poor;* and one, *none.* Following surgery there was no noticeable functional improvement in the ten hands with sensory defects rated *poor* or *none* preoperatively. The function of these hands was so markedly impaired due to the total involvement of the extremity that it was doubtful if the patients could learn to use them after surgery. The five hands rated *fair* preoperatively did not show an appreciable functional improvement. The extremely impaired sensation in these hands no doubt adversely affected the outcome of the surgery. Before undertaking surgery on the hand affected by cerebral palsy, the motor and sensory status of the involved upper extremity and of the patient as a whole should be carefully evaluated.

SUMMARY AND CONCLUSIONS

1. The results of the sensory examination of the hands of ninety-six children with cerebral palsy are presented. Sensory disorders were found in forty of the ninety-six patients (41.7 per cent).

2. The most common sensory defects in order of their frequency were: astereognosis, impairment of two-point discrimination and position sense. In addition to these, some patients failed to distinguish numbers traced lightly on the skin and were deficient in weighing perception, localization of tactile stimuli, sharp and dull discrimination, hot and cold discrimination, and in length measurement.

3. The practical significance of the above findings in orthopaedics is discussed.

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Fusion of the Spine for Tuberculosis in Children

A Long-Range Follow-up Study *

BY MATHER CLEVELAND, M.D., DAVID M. BOSWORTH, M.D., J. WILLIAM FIELDING, M.D., AND PANAYIOTIS SMYRNIS, M.D., NEW YORK, N. Y.

From the Orthopaedic Services of Sea View and St. Luke's Hospitals, New York

The material embodied in this paper comprises observations derived from eighteen of forty-two children who were treated by spine fusion for tuberculosis between the years 1929 and 1941. None of these patients had antituberculous medication, since the period of treatment was before its discovery.

Cleveland, in 1940, reported growth potentials occurring from young childhood to early adolescence when spine fusion had been performed for tuberculosis [1,2]. At the last meeting of The American Orthopaedic Association, Risser spoke on Vertebral Growth and Spine Fusion and Hallock and associates reported on Spine Fusion in Young Children as a Long-Term Study.

Other authors have, undoubtedly, contributed to this subject. The present authors claim no priority to observations. Half of the eighteen cases are patients reported by Cleveland in 1940; the cases are brought up to date. The other cases have not been reported. All are being studied as long-range follow-ups for the first time. Of the eighteen patients, two were easily located, for deaths in New York City are relatively easy to establish. This suggests to us that the number of those who died was small in the group we were unable to trace and that the over-all mortality was low.

Before one delves too deeply into the realm of statistics, it would be well to present a patient in order to demonstrate the human aspect of the problem (Fig. 1). Tuberculosis of the spine developed in a girl at the age of two and was treated conservatively. The disease steadily progressed until the girl was seen by us at four. A spine fusion was then done for disease of the third and fourth lumbar segments. The fusion extended from the first lumbar vertebra to the fifth lumbar vertebra and became solid. The patient was kept in bed for eighteen months. Since that time, she has been fully active. The concomitant abscess was resorbed and disappeared. She developed into womanhood, married, and now has three children. There have been no indications of recurrent tuberculous activity or of any other serious pathological condition in the interim.

THE PATIENTS

The eighteen patients on the whole came from very moderate circumstances (Fig. 2). Sixteen of the eighteen were in poor general condition at the time of operation. The average age at the time of operation was five and one-half years, the youngest being 1.9 years old and the oldest twelve years of age. As regards ethnic groups, there was no essential difference between one and another in recovery, given equal surgical, medical, dietary, and general physical care.

Two patients died of meningitis; both were boys. One of them had tuberculosis of the spine, hip, and shoulder. Both hip and shoulder were successfully fused. A solid spine fusion of adequate length was obtained. He disappeared from our observation in excellent condition. We heard of his death several years later. The other boy had very extensive tuberculosis of the cervicothoracic spine with destruction from the fifth cervical to the seventh thoracic vertebra, inclusive. Fusion was done in two stages. Further extension

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 31, 1957.

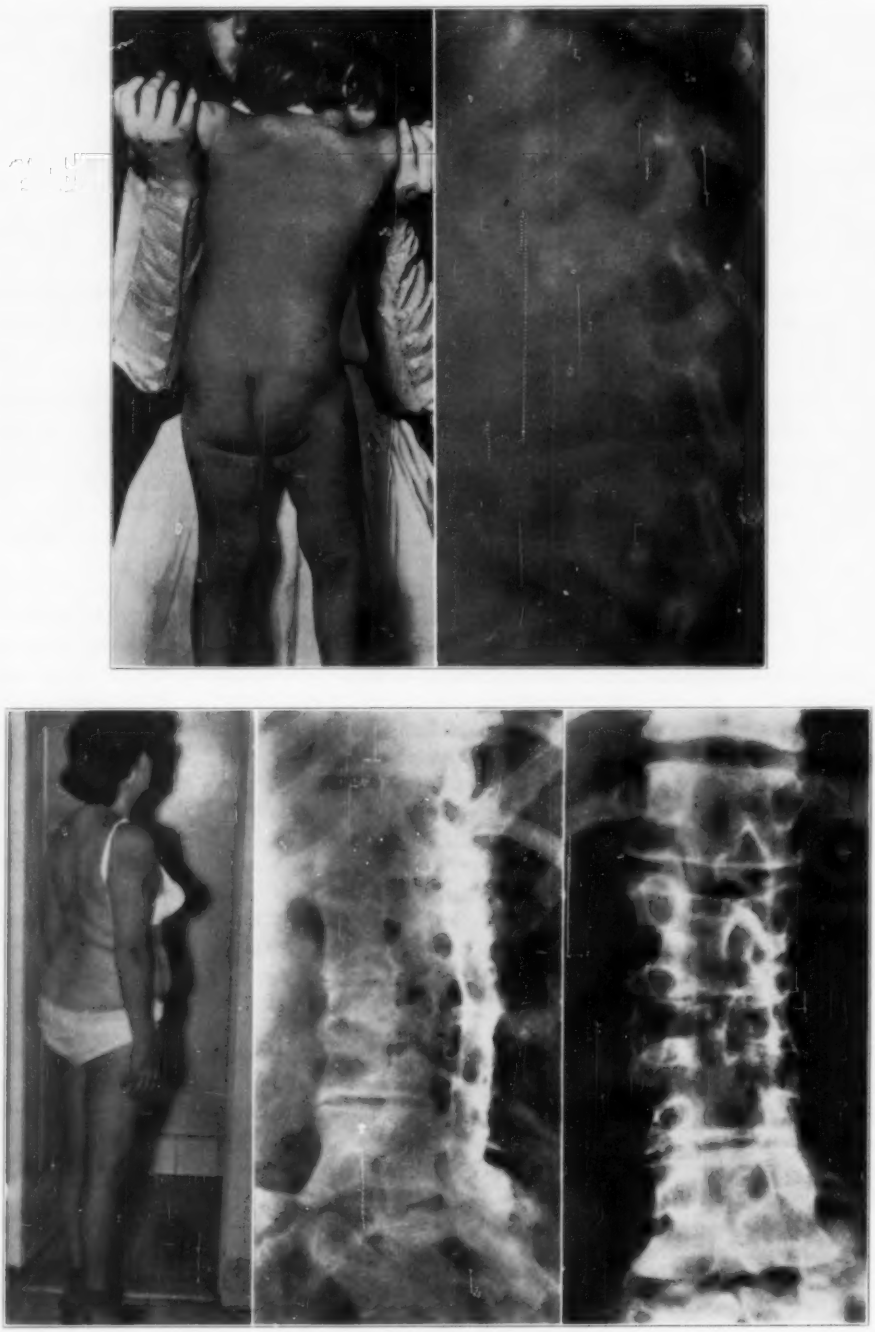

FIG. 1

This child developed into womanhood with a satisfactory lumbar fusion and has had three children with no complications or reactivation of tuberculosis. She, as were the other patients in this study, was treated before the era of antituberculous chemicals or antibiotics.

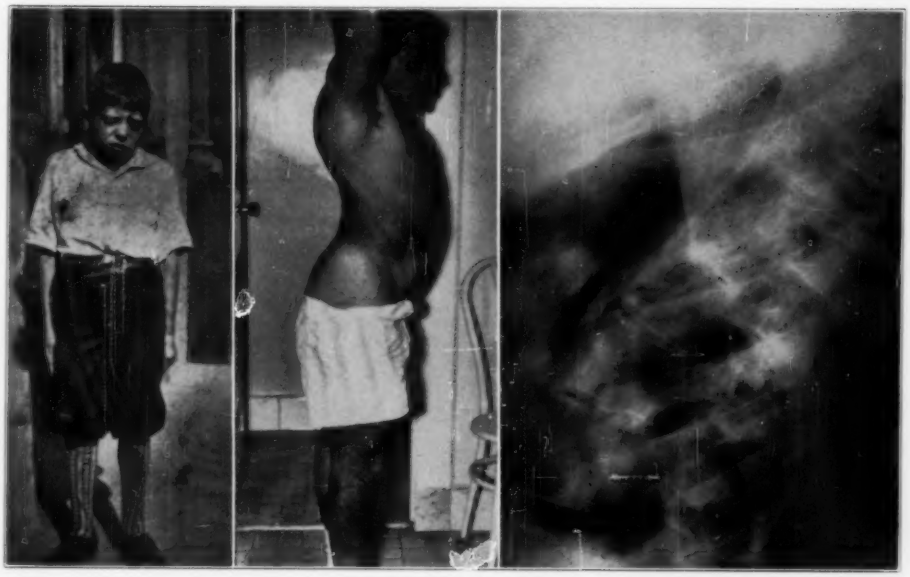

FIG. 2

Fig. 2: This boy shows the fairly impoverished status of most of the children comprising the original study.

Fig. 3: The extent of the abscess was always greater than the vertebral destruction. To be satisfactory, fusion needs to cover the full extent of the abscess, not merely the local destructive lesion of the spine.

FIG. 3

of fusion was advised, but he was removed by his parents against advice. He returned to us with paraplegia and sinuses from the spinal area and died.

Of the sixteen survivors at the present time, the average age is twenty-seven years, the oldest being thirty-six years of age and the youngest eighteen. The average time of follow-up postoperatively is 21.7 years, the longest being twenty-seven years and the shortest fifteen. The average period of disease preoperatively was twenty-one months. Fusion was done as soon as the diagnosis was made and the patient's condition permitted.

Tuberculosis involved the lumbar region in four patients. One patient had extensive involvement of the thoracolumbosacral region with fusion extending over seventeen vertebral segments from the second thoracic vertebra to the sacrum. Three patients had disease of the thoracolumbar region. Nine patients had tuberculosis of the thoracic area. One patient had involvement of the cervicothoracic region. The average number of vertebrae involved was five segments. The greatest number of vertebral bodies involved was ten. The extent of the abscess was usually considerably beyond the extent of vertebral involvement (Fig. 3) and necessitated a longer fusion than was indicated by the number of diseased vertebral segments. This was especially true in the thoracic area.

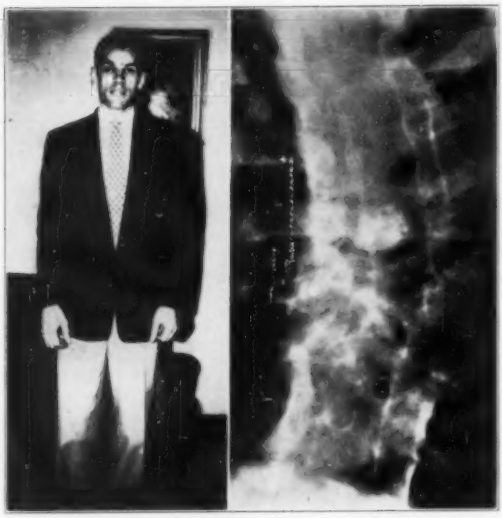

FIG. 4

Fig. 4: The man shown had paraplegia postoperatively and recovered to normal neurological status with no defects. Fusion alone accounted for the stabilization of the spine, decrease in the disease process and in abscess pressure, and recovery. In none of the patients in this series who were paralyzed was the abscess aspirated, incised, or drained.

The average number of segments involved in the lumbar area was two and a half; while the average number involved in the thoracic area was seven. This discloses the considerable destruction occurring in Pott's disease of the thoracic spine as compared with that in the lumbar spine. There were no instances in which separate isolated areas of the spine were involved.

Nine of the patients had demonstrable involvement outside the spinal column. There were tuberculosis of abdominal lymph glands, the eyes, skin, hip, foot, ribs, and shoulder. Almost every patient had evidence of either pulmonary lesion or involvement of the mediastinal lymph glands.

There were two patients who had paraplegia preoperatively (Fig. 4). Both of these recovered from paraplegia and it did not recur following successful fusion. In three patients, paraplegia developed following the first attempt at fusion. One of these was the boy who later died of meningitis and in whom the tuberculous lesion was never adequately

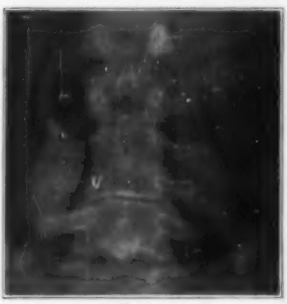

FIG. 5

FIG. 6

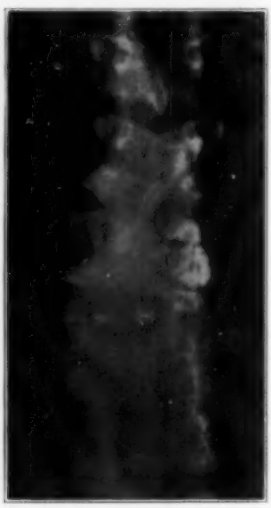

FIG. 7

Fig. 5: Discrimination between abscess shadow and calcified lymph glands was important in denoting extent of fusion. Frequently, the demarcation between these conditions was not as clear as in this illustration.

Fig. 6: In these patients abscess resorption after spine fusion was usually complete. Occasionally, residual shadows were present but frequently these represented not residual abscess but residual calcified lymph glands. (Fig. 5 shows the preoperative condition in this patient in youth.)

Fig. 7: Final roentgenogram of the spine in one of two patients who had residual sequestra, apparently inert. Both patients were asymptomatic and were in excellent general condition.

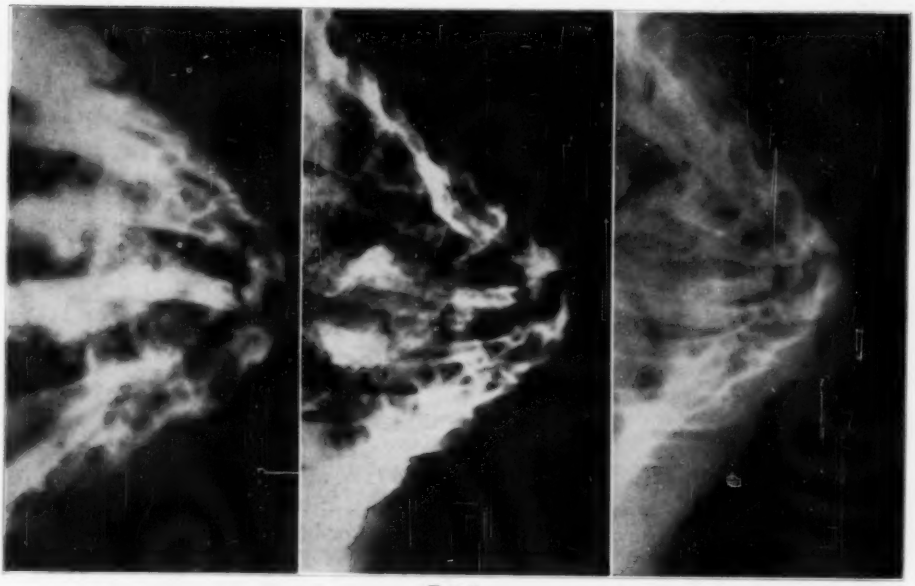

FIG. 8

Roentgenograms of a patient with a continuous fusion (albeit tenuous), in whom fatigue-stress pseudarthrosis developed. Within seven months, the pseudarthrosis was spontaneously bridged and repaired. When severe disease is present in a child, additional amounts of autogenous iliac bone may be necessary for reinforcement at the apex of the kyphos. This may be done during a second operation, if necessary.

covered by the fusion. The second became paraplegic without development of a pseudarthrosis during the subsidence of the lesion after fusion. He recovered completely. In the third patient paraplegia developed and was associated with a pseudarthrosis which was successfully repaired; the patient recovered. There is among the whole group of sixteen living patients followed at this date no evidence of neurological change indicating cord or nerve-root pressure. None of the eighteen patients exhibited radicular symptoms at any time despite collapse of vertebral segments and reduction in size of the intervertebral foramina.

Twelve of the eighteen patients had demonstrable abscesses as differentiated from widened mediastinum and lymph-node involvement (Fig. 5). In five no definite abscess was demonstrable. One patient had a neck sinus which drained the lesion and prevented abscess formation. Seventeen patients never had a sinus. Despite the fact that no aspiration, drainage, or evacuation of abscesses was done, only six show any residuum of the previous abscess at this time (Fig. 6); these are small and well calcified. There are two patients who still show definite inert sequestra in the thoracic area (Fig. 7).

In the eighteen patients, thirty-five spine fusion operations were done as primary procedures and nine pseudarthroses were repaired. There were no postoperative deaths or other major complications. Many of the patients had fusions done in more than one stage. One patient had definite evidence of disease of the posterior elements of the spine. In this patient pseudarthrosis developed after fusion without extra bone. A second attempt to gain fusion failed when no extra bone was used; fusion was finally obtained on a third attempt when extra autogenous iliac bone was used.

The operative procedure in all instances was basically a Hibbs' fusion. Four patients had reinforcement of the fusion area with tibial chips; fusion occurred in three. In five patients the fusion area was reinforced with iliac strips, and fusion became solid in four. Of nine patients with an unreinforced fusion area, fusion failed in six — one at two

locations. Once we had learned to reinforce the fusion with extra bone, the incidence of pseudarthrosis was greatly reduced.

The average length of the fusion was nine spinal segments. The shortest fusion was four and the longest was seventeen segments.

In one of the patients (Fig. 8) during eight months' time, fusion occurred, pseudarthrosis developed, and the pseudarthrosis healed spontaneously. Further angulation of the kyphos occurred during this process. This brings up the question whether fusion in children actually slowly bends or whether spontaneous fatigue stress fracture of the grafted area occurs, pseudarthrosis develops, and thereafter heals unnoted. It further suggests that in children with severe Pott's disease of the thoracic spine massive amounts of bone should be added subsequent to the original fusion. Five pseudarthroses developed in the thoracic area and four in the lumbosacral region. In the thoracic area, the pseudarthrosis always developed at the apex of the kyphos. In the lumbar area it developed just above or below the diseased bodies, not at the apex of disease. All attempts at repair of a pseudarthrosis were eventually successful. No pseudarthroses are present at this time as determined by roentgenogram, by clinical examination, or by progress of the lesion, except in one patient who has an asymptomatic failure of fusion outside the area of disease.

FIG. 9

Disproportion of the trunk *versus* the extremities occurred in five patients, usually with severe involvement of the thoracic spine.

PRESENT CLINICAL STATUS

Of the sixteen patients who survived, nine are in excellent condition and are essentially normal as judged by physical activity. Four are excellent, but because of moderate kyphosis apparent when unclothed, they cannot be considered normal. Two have considerable kyphosis which is apparent even when the patient is clothed. One has marked deformity, impossible to mask by clothing, with great constriction of the chest and loss of abdominal as well as thoracic space. All of the patients with primary lumbar involvement had excellent results.

Disproportion (trunk *versus* extremities) is marked in one instance (Fig. 9), considerable in two, and noticeable in two. Four have some disproportion on measurement, not noticeable when they are clothed or unclothed.

Four of the girls have grown up and married and two of them have children, one three and the other two (Figs. 10-A and 10-B). Two of the men are married and both are fathers. All the children are alive and well. There is no record of abortion or of sterilization required. There is no evidence of transmission of tuberculosis to the offspring.

Social adjustments are excellent in ten patients who lead a normally productive existence. In three they are very good, in two they are moderately limited, and in one

FIG. 10-A

FIG. 10-B

Four of the patients, two men and two women, have families. Roentgenograms of the spine of two of the patients show the results of extensive disease. The man whose spine is shown on the right had complete paraplegia as a child and recovered following fusion. The fact that a woman with tuberculosis of the spine, arrested by fusion, can safely have children and a normal home is not generally realized.

adjustment is considerably limited. All those who had lumbar disease have made excellent adjustment. The present occupations of the patients include activities such as actress, seaman, factory worker, clerk, tree surgeon, carpenter, and housewife. The original contact with tuberculous disease is noted as being through the father or mother in six patients and unknown in the others.

On clinical and roentgenographic examination, there was no apparent retardation of growth of the bones of the extremities incidental to spinal disease. Disproportion of the extremities with the trunk occurred when severe shortening of the spinal segment was present. No gross disproportion occurred when involvement was confined to the lumbosacral spine.

No gross deformation of the thorax occurred with involvement of the lumbar spine (Fig. 11). Deformation of the thorax did occur and was directly related to the amount of involvement of the thoracic spine and particularly to the area of involvement. In all patients with thoracic involvement as seen by roentgenogram, the thoracic cage became squared, smaller in content, and lowered toward the pelvis. This again was greater with involvement of the upper thoracic region as compared with that from involvement of the lower thoracic or thoracolumbar region. Mild flaring of the lower ribs was noted in patients with disease of the lumbar spine.

Thoracopelvic approachment (Fig. 12) was much greater in patients with thoracic involvement than in those with lumbar involvement. Average decrease of the thoracopelvic distance was 46 per cent and varied from 0 to 100 per cent.

Loss of lordosis occurred in patients with lumbar lesions, but much less than one would expect when compared with the amount of involvement of vertebral-body struc-

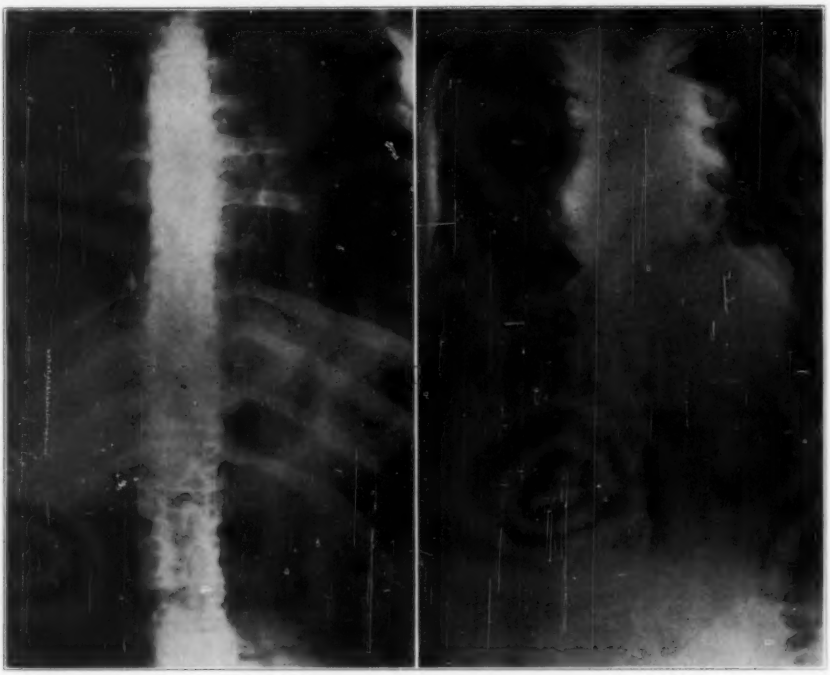

FIG. 11

Lumbar disease did not greatly alter the contour of the thorax. Thoracic disease caused the shape of the thorax to become box-like, with considerable deformation of the ribs.

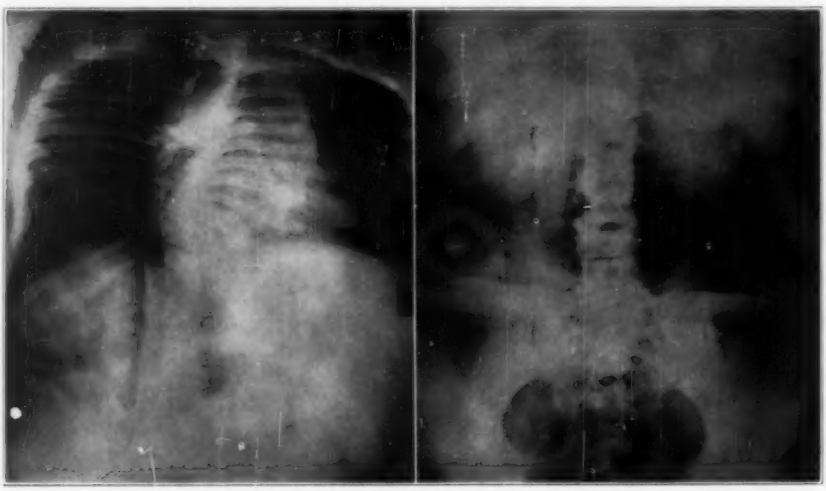

FIG. 12

When thoracic disease occurred, the thorax was always lowered upon the pelvis. With lumbar disease, on the contrary, lowering of the thorax toward the pelvis was slight. Note the descent of the rib cage beyond the iliac crests with thoracic disease and the good abdominal space with the rib cage held well above the iliac crests when lumbar disease was present.

tures. Kyphosis in the thoracic area always occurred. It was rounding if a considerable vertebral segment was involved and pseudarthrosis had not occurred. It was sharp and angulated if pseudarthrosis occurred (Fig. 13) and was apparently related to the leverage of fusion above and below the pseudarthrosis rather than to localized vertebral-body

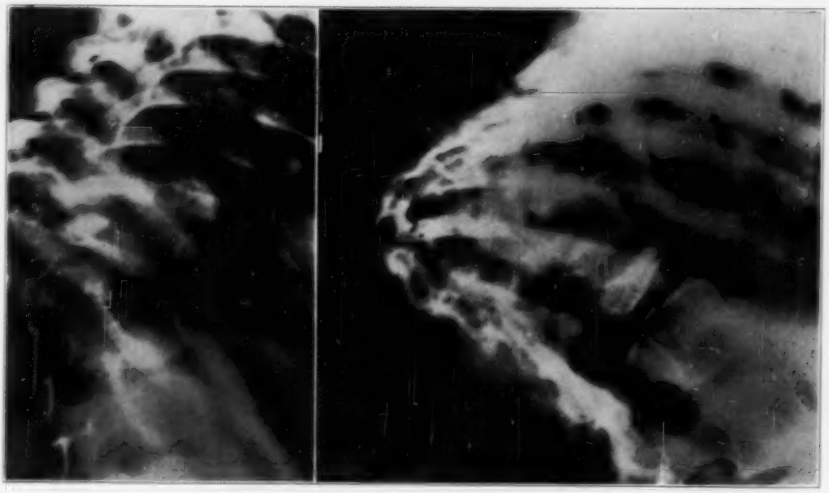

FIG. 13

When fusion arrested the disease and became solid, there was no sharp angulation of the kyphos. When pseudarthrosis occurred, sharp angulation of kyphos resulted. This apparently developed due to the leverage of the fusion above and below the pseudarthrosis. In this instance, no paraplegia ensued despite the considerable kyphos.

FIG. 14

FIG. 15

Fig. 14: This roentgenogram made at a later time in the same patient shown in Fig. 13 shows total destruction of nine vertebral bodies between relatively uninvolved bodies which lie in side-to-side contact.

Fig. 15: In one patient, with marked thoracic disease, the bodies below were considerably expanded in a vertical direction. This apparently resulted from the decrease of pressure upon them incidental to the lordosis produced by the kyphos above.

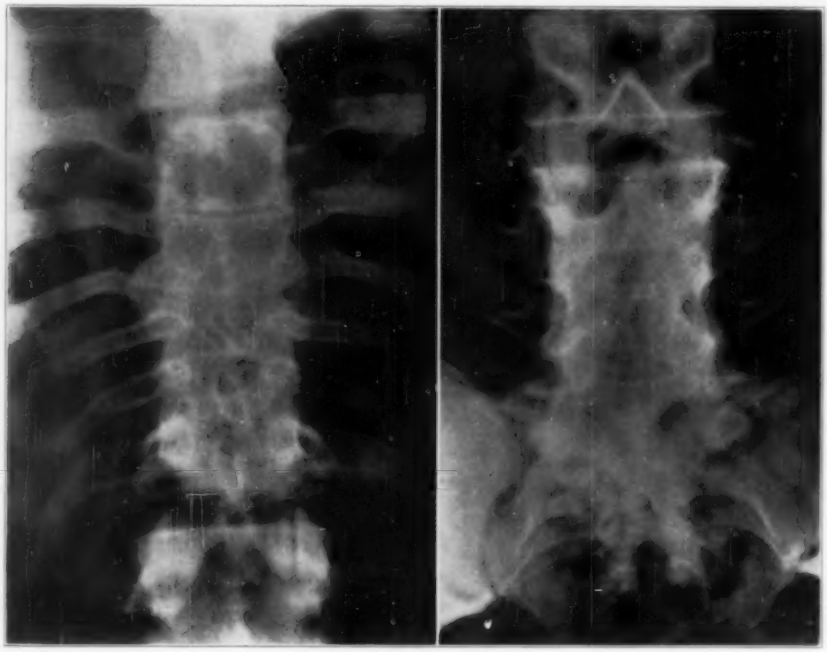

FIG. 16

When fusions of the lumbar spine or of the thoracic spine ended in the lumbar region, sudden marked lateral expansion of the vertebral segment at the end of the fusion occurred. If a fusion from below terminated in the lumbar region, the lumbar transverse processes turned upward. If fusion from above terminated in the lumbar region, the lumbar transverse processes turned downward. This was apparently related to the pull of ligamentous and muscular attachments from normally developing structures upon those restricted in their growth by fusion and disease.

destruction. Of the twelve patients with lesions in the thoracic or thoracolumbar region, there was one who had an extreme kyphosis (Fig. 14) with loss of nine vertebral bodies. Two others had severe sharp angulated kyphosis, and four had considerable rounding kyphosis, not sharply angulated. Three had mild kyphosis, not noticeable when the patient was clothed. In two instances, the kyphos was so small or so gentle in its development that the patient appeared clinically normal or seemed to have had a mild vertebral osteochondrosis.

Compensatory lordosis in the cervical and thoracic regions was present when thoracic involvement occurred; this was considerable in one patient, moderate in six patients, and slight in the others. In the latter patients, the region for compensatory lordosis was long enough to provide gradual compensation. If the compensatory curve in these patients had been confined to a short area, it would have appeared considerably greater.

There were no patients in whom changes in the pelvis or sacro-iliac joints occurred either by primary involvement or deformation due to the tuberculous spinal lesion. One patient with a hip fusion had considerable unilateral deformation of the pelvis. No defects were demonstrable in the pelvis or in the tibia incidental to removal of graft material during childhood.

ROENTGENOGRAPHIC FINDINGS IN THE FULLY DEVELOPED ADULT

For the first two or three years density of the fusion mass was increased but as age advanced, particularly in this final adult study, decrease of density of the fusion mass was noted; this despite the fact that the fusion mass itself had increased in size.

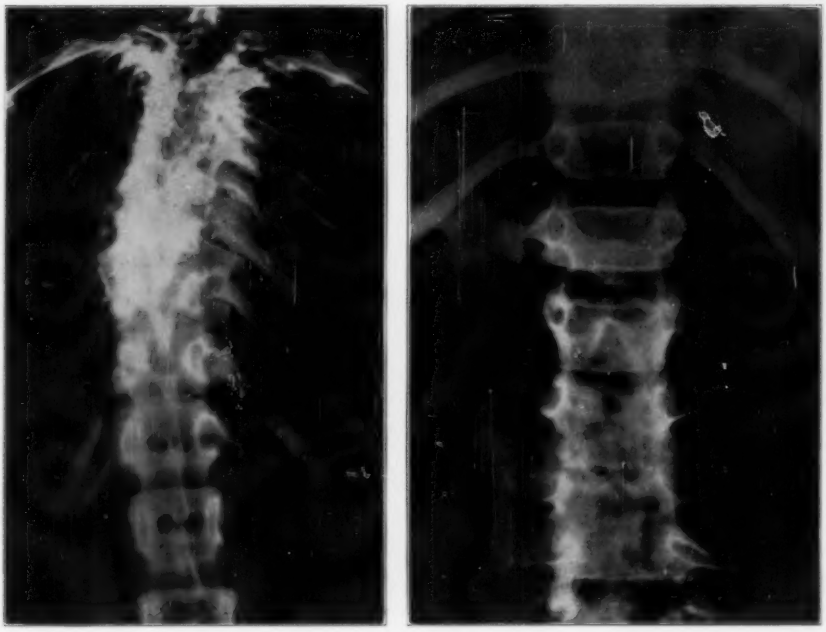

FIG. 17

When fusions terminated within the thoracic region, expansion of the vertebral bodies from the fusion to the normal structure was gradual. Comparison is made between the thoracic fusion and the lumbar fusion in this respect. Note again the marked differences in effect on the rib cage caused by thoracic as against lumbar fusion and disease.

Growth of the fusion mass itself was noted to occur. The average growth in length of the fusion mass, on comparison of the measurements made on the preoperative roentgenograms with those made on the present roentgenograms, was one and one-half inches; the least growth in length was three-quarters of an inch. The average increase or growth in thickness of the fusion mass in an anteroposterior direction was five-eighths of an inch; the average growth in lateral expansion of the fusion mass was three-eighths of an inch.

The average loss of length in the fused tuberculous spines varied directly with the area involved (lumbar as against thoracic) and with the original amount of destruction. Undiseased bodies not included in the fusion exhibited normal growth.

The average in roentgen measurements as hereafter described has been determined by comparison of the measurement of the fused segments of the tuberculous spine with those of the normal spine. Vertebrae in roentgenograms of normal adults were compared with vertebrae not included in the disease or fusion area of each patient. Thus by noting the difference in measurements between the uninvolved vertebral segments of the patients and the vertebrae of normal persons, we were able to reasonably reconstruct to scale what the dimensions of the destroyed or fused segments should have been, if their growth had not been altered.

The average loss of the over-all length of the spinal area included in these fusions, as compared with the normal, was 49.1 per cent. It varied from 21 per cent in the lumbar to as high as 66 per cent in the thoracic region. The average loss in vertical height of the uninvolved vertebral segments included in a fusion was 16.1 per cent. The average loss in vertical height of the diseased segments included in the fusion was 57.2 per cent.

The lateral diameter of the diseased body mass in the fusion area, as compared with the normal, decreased at an average of 16.4 per cent. The lateral diameter of the undiseased

FIG. 18

FIG. 19

Fig. 18: Discs at the end of fusion areas were routinely expanded beyond the normal for one or two segments.

Fig. 19: There was no evidence of calcification of discs included in the fusion but not involved by disease. Ankylosis of the posterior margins of uninvolved discs included in the fusion area did occasionally occur along the posterior ligamentous structures.

body mass decreased by an average of 15 per cent. The anteroposterior diameter of the diseased body mass in the fusion area decreased by an average of 29.5 per cent, and the anteroposterior diameter of the undiseased body mass by 20.5 per cent. It should be noted again that the vertebral segments outside the fusion area presented essentially normal measurements and apparent normal growth. In one patient, however, with an extreme thoracic kyphos and a marked lumbar lordosis, there was vertical expansion of the vertebral bodies in the lordotic area of the lumbar region (Fig. 15). This we believe to be related to the relief of pressure on the vertebral bodies anteriorly due to support through the arches and facets posteriorly.

A prominent feature noted was lateral and anteroposterior expansion of that portion of the body at the terminal end of a fusion lying in the lumbar region or at the thoracolumbar junction (Fig. 16). When a fusion ended within the thoracic area such sudden expansion did not occur (Fig. 17). There, the expansion to the size of the normal segments above or below, was gradual. It is possible that the thrust of the ribs, or some similar factor, may prevent sudden expansion.

The average loss of height of intervertebral-disc structures included in the fusion was 75.2 per cent. Total loss of intervertebral-disc structure always occurred in the diseased area. Disc structure was always present, although decreased in thickness, between the undiseased elements included in the fusion.

It cannot be truly held, as suggested, that vertebral bodies included in a fusion grow at the expense of the disc. The average loss of body growth adds to the picture of over-all

FIG. 20

FIG. 21

Fig. 20: Ankylosis of the vertebral bodies involved by disease within the fusion area routinely was essentially complete.

Fig. 21: Occasional sclerotic markings within the synostosed masses of the involved vertebral bodies remained. These indicated original disc remnants.

shortening of the fused segment whether diseased or undiseased. It is true that the disc loss is greater percentagewise than that of the vertebral bodies, but it is the total suppression or loss of the discs in the diseased area and the collapse of the diseased bodies that cause the greatest amount of such loss of growth. Outside the fusion area, disc growth is essentially normal. In no instance was there any indication of disc laceration at either end of the fusion area incidental to the leverage action of the fusion. In numerous instances discs at the ends of fusion were expanded beyond the normal in thickness (Fig. 18). There was no evidence of calcification of discs between uninvolved segments included in a fusion (Fig. 19). Occasional ankylosis of the undiseased vertebral bodies included in the fusion area, at their posterior margins, was noted, as though ossification had occurred along the posterior longitudinal ligament (Fig. 20). This was not always present. Ankylosis of the vertebral bodies within the diseased area was essentially complete. There were occasional sclerotic markings within such ankylosed masses representing the location of previous disc structures (Fig. 21).

In all patients, the laminae and articular facets lost their identity in the fusion mass. This occurred in both the diseased and undiseased portions of the fusion. The pedicles showed marked atrophy within the diseased area, losing vertical height and lateral expansion as well as being greatly shortened. Similar changes, but of lesser extent, were present in the undiseased segments included in the fusion. In the lumbar area posterior bowing of the fusion mass had occurred without equal kyphosis of the included bodies, giving an appearance of a lengthened pedicle (Fig. 22).

The spinal canal in the lumbar area was usually larger in the mid-portion of the fusion area regardless of the location of the diseased body and smaller at the ends, so that it appeared fusiform. In the thoracic area, the reverse was true, and marked narrowing was

FIG. 22

FIG. 23

FIG. 24

Fig. 22: In the lumbar area, the pedicles appeared lengthened due to the apparent bowing of the fusion mass posteriorly, giving the appearance of a wider canal in the mid-portion of the fusion area than at the ends.

Fig. 23: In the thoracic area the canal was narrowest at the apex rather than apparently expanded. In both the thoracic and the lumbar areas, the intervertebral foramina became rounded and smaller depending upon the extent of disease and the age at which fusion was done.

Fig. 24: In a child, a fusion can arrest the disease with healing occurring without contact of vertebral bodies. Note the gap in the vertebral bodies just above the kyphosis. To accomplish this, the use of extra autogenous iliac bone to reinforce the grafted area is essential. In children, such a residual gap in the fused spine is rarely seen since re-ossification of the area of destruction usually occurs.

present opposite the diseased area whether the kyphosis was severe or not (Fig. 23). This narrowing was increased as the kyphosis became more severe. In all areas included within the fusion, the canal was definitely narrowed on comparison with the normal. Narrowing of the canal in the kyphos in the thoracic region amounted to as much as 66 per cent on occasion and to as little as 20 per cent when a severe kyphos did not exist as in the lumbar region. Shortening of the spinal canal corresponded to shortening of the involved vertebral segments.

In all instances, total ankylosis and coalescence of the diseased bodies had occurred except in one patient in whom the fusion had apparently arrested the disease, leaving a gap (Fig. 24). In three of the patients, residual sequestra still remained within the coalesced mass of vertebral bodies. These suggest, therefore, the possibility that the fusion held the destroyed vertebral segments apart. Therefore, the statement that in children the disease is never arrested until the vertebral bodies have come in contact may not invariably hold true.

The intervertebral foramina in all regions became round in shape and smaller in size. The lessening in size of the intervertebral foramina was directly related to the amount of destruction. In badly diseased and kyphotic areas, the foramina were very small.

The transverse processes were markedly atrophied in the destroyed thoracic areas and showed moderate atrophy in the undiseased segments included in thoracic fusions. In the lumbar and lumbosacral region, the transverse processes remained essentially normal in length. Frequently, lumbar processes were seen to hypertrophy. When fusions from above terminated in the upper lumbar region, the lumbar transverse processes

FIG. 25

Tuberculosis of the spine in a child adequately treated by spine fusion can result in an excellent physical condition in the adult. This result, of course, can be more routinely and more rapidly obtained since the development of antituberculous chemicals and antibiotics.

turned downward. When fusions existed solely in the lumbar and lumbosacral region, the transverse processes uniformly were directed upward (Fig. 16). Apparently, the pull of muscular and ligamentous attachments arising from normally growing structures altered the direction of the processes of vertebral segments whose growth was retarded by disease and fusion.

The spinous processes remained as well defined structures in the lumbar area but were almost completely lost in the fusion mass in the thoracic region. In no instance could ankylosis of the costovertebral joints be demonstrated by roentgenograms, even in severely deformed and diseased areas.

CONCLUSIONS

1. Spine-fusion masses grow and of themselves cause minimal deformity.

2. In a child with tuberculous spondylitis, spine fusion can decrease or may prevent collapse of diseased vertebral bodies.

3. No residual pelvic defects were noted in these adults as a result of removal of iliac grafts from them as children.

4. Development of kyphosis may at times be the result of fatigue-stress fracture of the fusion mass with spontaneous repair occurring unnoted.

5. Paraplegia in a child, due to vertebral tuberculosis, demands spine fusion, not laminectomy or evacuation of abscess.

6. Tuberculosis of the spine in a child, adequately treated by spine fusion, can result in an excellent physical status in the adult (Fig. 25).

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Cervical Intervertebral-Disc Calcification in Children

BY THOMAS HANS NEWTON, M.D., BOSTON, MASSACHUSETTS

From the Department of Radiology, Children's Medical Center, Boston

Intervertebral-disc calcification is common after the fifth decade of life when it is thought to represent a degenerative process. It has rarely been reported in children; however, when it has, the clinical course and pathogenesis appear more variable and less certain.

Twelve children with cervical-disc calcification have previously been reported[5,7,8,10,11,13,14,15]. Most of these have been reviewed in the comprehensive papers of Weens and Silverman.

Ordinarily, calcified cervical discs in childhood have been found associated with symptoms or clinical signs. The calcification usually clears rapidly. Calcified thoracic and lumbar discs, by contrast, have often been found incidentally, and are generally multiple, asymptomatic, and persistent. A definite association with congenital heart disease has been reported in this group.[14]

FIG. 1-A

FIG. 1-B

FIG. 1-C

Roentgenograms made at age seven years and three months (Figs. 1-A and 1-B) show slight straightening of the normal cervical lordosis above the fifth cervical vertebra. There is dense calcification of the nucleus pulposus between the sixth and seventh cervical vertebrae as well as calcification in the tissues anterior to the fifth interspace. Follow-up roentgenogram (Fig. 1-C) made at age eighteen and one-half years reveals a normal cervical spine.

In the past twelve years, seven children with calcified cervical intervertebral discs have been observed. In light of the sparcity of previous reports these are briefly presented and reviewed.

CASE 1. R.S., #217286, a white boy, seven years and three months of age, was admitted to the Children's Medical Center on November 24, 1944, complaining of a stiff neck. Six days prior to admission, he had fallen from a height of five feet and had landed on the back of his neck, but had no apparent injury or immediate symptoms. However, three days later, his neck became stiff and his head was slightly tilted to the right. He had no neck pain. The patient had been perfectly well, although he had been in a minor automobile accident six months before. Positive physical findings were limited to the neck. The head was bent toward the right shoulder, with the chin slightly rotated to the left. There was limitation of active and passive rotation, neck extension, and bending to the left. The result of the Hinton test was negative. The result of the tuberculin test was negative, 1:1000. The white blood cell count was 12,900. The neck was kept in traction by means of a Sayre head sling. He was discharged on the fifteenth hospital day with his head and neck in

a normal position. He had slight limitation of motion on left bending and on turning his chin to the right. When last seen in 1956, eleven and one-half years later, he was completely asymptomatic (Figs. 1-A, 1-B, and 1-C).

Case 2. J.T.M., #272747, a white boy, five years old, was admitted to Children's Medical Center on April 29, 1945, with a two-week history of pain in the left shoulder and neck. After he was allegedly pushed down a flight of stairs, the shoulder pain began. The pain became progressively worse and spread to the lower portion of the neck. Physical examination showed a child in obvious discomfort. The head was held in 10 degrees of hyperextension and 10 degrees of flexion to the left. Flexing his head elicited pain in the left posterior cervical region and over the left trapezius. Rotation to the left was 70 degrees and to the right

Fig. 2-A

Fig. 2-B

Fig. 2-C

Fig. 2-D

Calcification of the intervertebral disc between the fifth and sixth cervical vertebrae was first noted in 1943 at age three years, at which time there were no neck symptoms (Fig. 2-A). Some resolution of this calcification had occurred two years later when roentgenograms were made two weeks after the onset of neck pain (Figs. 2-B and 2-C). Examination eleven years later (Fig. 2-D) shows a normal spine with complete disappearance of the disc calcification.

50 degrees. There was slight tenderness and spasm over the left deltoid and trapezius. The result of a neurological examination was negative. Urinalysis was negative. White blood cell count ranged from 13,200 to 16,900 with a normal differential. Spinal-fluid examination showed five monocytes per cubic millimeter, but was otherwise normal. The result of the Hinton test was negative, and the tuberculin test was negative, 1:1000. The patient was placed in head traction with a Sayre sling, and hot packs were applied to his left shoulder and neck. Two weeks after admission, head traction was discontinued and a Thomas collar was applied. The patient was discharged on the sixteenth hospital day, with full range of painless neck motion

and no local tenderness or muscle spasm. When last seen on June 13, 1956, eleven years later, he was completely asymptomatic (Figs. 2-A, 2-B, 2-C, and 2-D).

CASE 3. B.L.B. (private patient of Dr. William T. Green), a six-year-old white boy was first seen on December 27, 1950. After a fall from a tree one year before, he had complained of occasional pain in the neck, especially with twisting or sudden motion. General physical and neurological examination was non-contributory. He protected his neck in all motions. There was tenderness over the sixth and seventh cervical vertebrae on direct pressure. Blood studies and urinalysis were normal and the result of a tuberculin skin test was negative. He was placed in a Thomas collar but showed very slow improvement. He continued to have neck pain and limitation of neck motion. Two and one-half years after the initial onset of neck symptoms he became asymptomatic and was so at his last follow-up visit in July 1956.

Roentgenographic examination: Irregular calcification of the disc between the fifth and sixth cervical vertebrae was found on December 27, 1950. The normal cervical lordosis showed slight disalignment, probably secondary to muscle spasm. Follow-up roentgenograms made on July 27, 1951, and January 7, 1952, showed the disc calcification to be slightly more prominent. On July 12, 1956, definite regression was noted, but a small fleck of calcification was still present.

CASE 4. P.G., #375683, a ten-year-old white boy, was admitted to Children's Medical Center with a six-hour history of paralysis of all extremities and respiratory difficulty. He had been well until five days before admission when a sore throat and fever of 103 degrees developed for which he was treated with penicillin. Two days prior to admission severe occipital headache, sore throat, and vomiting developed. Rapidly progressive paralysis began to develop starting in his arms and spreading so rapidly that within one and one-half hours he was unable to sit up or roll over. His respirations became irregular and on arrival at the hospital he was cyanotic and needed artificial respiration. Physical examination showed an acutely ill, cyanotic boy with irregular shallow respirations. His temperature was 100.5 degrees. Positive findings were all neuromuscular. There was a total flaccid paralysis of all extremities, the trunk, and the neck. Respirations appeared to be mostly left diaphragmatic and no intercostal muscle action was noted. There was no response to pin prick below the level of the fourth cervical vertebra. Bladder and rectal sphincters were inactive. Deep tendon reflexes and superficial reflexes were absent. There was a positive Babinski sign on the left and a questionable Babinski sign on the right. There was no neck stiffness. Repeated urinalyses and blood counts were normal. Multiple lumbar punctures were entirely normal. The result of the tuberculin skin test was negative, 1:1000. Blood determinations, heterophil and febrile agglutinins, liver function studies, and electroencephalograms were normal. The clinical impression was transverse myelitis of unknown etiology at the level of the fourth cervical vertebra. ACTH and terramycin therapy were started on the second hospital day and there was rapid steady improvement. Initially, he was placed in a tank respirator but was gradually weaned to a rocking bed. During the second week he was able to breathe unassisted. At discharge, two months later, most of his muscles had returned to normal and the sensory defect was no longer present. Bowel and bladder control had again been established. Isolated muscle weakness in his right shoulder girdle and slight thoracolumbar scoliosis were the only residual changes five years later (June 1956).

Roentgenographic examination: Dense calcification of the nucleus pulposus between the fourth and fifth cervical vertebrae was noted on the day after admission. The cervical spine otherwise appeared normal except for slight flattening of the normal lordotic curve. A faint, hazy, increased density was still present within this interspace five years later. The structure of the cervical spine was otherwise normal.

CASE 5. J.W., #269803, a ten-year-old white girl, was well until three weeks prior to admission on March 13, 1954. At that time, she noted the onset of a painful neck and a tendency to hold her head tilted to the right. No history of trauma was elicited. Positive physical findings were limited to the neck. The head was tilted 40 degrees to the right and the chin was rotated 20 degrees to the left. She was unable to extend her head. The left trapezius and the right omohyoid muscles were sensitive and in slight spasm. Routine laboratory studies were normal. She was placed in head traction and had a normal range of neck motion without muscle spasm on the second day. She was discharged on the third day in a Thomas collar and with a full range of painless neck motion. When last seen in May 1956, she had full range of motion of the neck but still complained of intermittent neck pains (Figs 3-A, 3-B, and 3-C).

CASE 6. S.W., #438538, a seven-year-old white boy, was admitted to Children's Medical Center on March 13, 1956. He had been in excellent health until ten days prior to admission when he had a fever of 101 degrees associated with sore throat, headache, and stiff neck. These symptoms disappeared within three days on penicillin therapy. He was then well until two days prior to admission when he noted persistent non-radiating pain, aggravated by motion, in the dorsal aspect of the neck. General physical examination was normal except for a fever of 101 degrees. The boy sat with the head flexed forward and both shoulders elevated. There was marked limitation of forward flexion, but rotation was free in either direction. Urinalysis was negative. Hemoglobin was 12.6 grams per 100 cubic centimeters. The white blood cell count was 17,000 with a normal differential. The corrected sedimentation rate was 33. Cerebrospinal fluid was negative.

The result of the tuberculin test was negative, 1:1000. The patient was placed in cervical traction and was given achromycin. He became afebrile within forty-eight hours. The neck pain subsided rapidly and on the fourth day he had full range of painless motion. He has been followed in the out-patient department and has remained asymptomatic (Figs. 4-A, 4-B, 4-C, and 4-D).

CASE 7. L.L., #443226, a three-year-old white boy, was admitted on May 2, 1956. He had been in excellent general health until April 28, 1956, when he began to complain of stiff neck and pain on motion. There was no history of trauma. The pain and limitation of neck motion gradually became more severe until he was first seen at the Children's Medical Center, five days after the onset of symptoms. Positive findings were limited to the neck. The head was held rigid with resistance of motion in all directions but especially on turning the head to the right and on extension of the neck. There was slight spasm of the trapezius on the left. The patient improved rapidly with the application of heat, massage, and aspirin and was clinically well five days later, having full range of painless neck motion.

FIG. 3-A

FIG. 3-B

FIG. 3-C

Initial examination (Figs. 3-A and 3-B) showed irregular amorphous calcification of the nucleus pulposus between the fourth and fifth cervical vertebrae and of tissues anterior to this interspace. Four years later (Fig. 3-C) there was only partial resolution of the disc calcification while the calcification of the prevertebral tissues had disappeared. A break in the normal cervical lordosis at the level of the fourth cervical vertebra was noted as well.

Roentgenographic examination: Roentgenograms made on May 2, 1956, showed the cervical spine to be normal except for a faint calcification of the disc between the third and fourth cervical vertebrae. This calcification showed partial resolution on a second examination three weeks later.

OBSERVATIONS

Review of these seven cases and of the twelve others reported in the literature reveals many interesting observations.

Age: The age at the time of the initial symptoms and diagnosis varied from two and one-half to eleven years with an average of seven and one-half years.

Sex: A marked preponderance of males was noted with fifteen boys and three girls. In one case, sex was not stated.

Predisposing factors: A recent head or neck injury which seemed to initiate the illness was noted in only six patients. Seven patients had slight to moderate fever, just prior to, and during, the onset of symptoms. Some of these seven had associated sore throats. Six of the nineteen patients had sudden onset of neck symptoms without any preceding illness or obvious injury.

Symptoms: All but one patient had complaints referable to the neck. These complaints consisted usually of pain associated with limitation of neck motion and torticollis. The patient (Case 4) who had no neck symptoms had transverse myelitis at the level of the disc calcification.

Clinical course: Most patients were symptom-free within two weeks. Two of our patients (Cases 3 and 5), however, continued to have occasional neck pain for over two years. It is interesting that these two patients still had a slight residual disc calcification and abnormal cervical spine alignment several years after the initial illness.

Roentgenographic appearance: Calcifications occurred in all interspaces from the second to the seventh cervical vertebrae; the highest incidence was in the lower cervical

FIG. 4-A

FIG. 4-B

FIG. 4-C

FIG. 4-D

There was faint calcification of the nucleus pulposus between the sixth and seventh cervical vertebrae on the initial examination ten days after the onset of symptoms (Fig. 4-A). In addition, there was denser calcification apparently in the cartilaginous plates of this disc as well as a dense rounded calcification lying anterior to this interspace. The intervertebral-disc spaces were maintained in height. Roentgenograms made three weeks and two and one-half months later (Figs. 4-B and 4-C) showed rapid regression of these calcifications. Five months after the initial examination, the cervical spine appeared normal (Fig. 4-D).

spine. Most of the calcifications were located centrally in the disc, presumably in the nucleus pulposus. Four patients (including one of ours) had calcification of more than one cervical disc. Three of our patients had calcification in the tissues anterior to the affected interspace. This finding had not previously been reported. These three patients, except for their unusual roentgenographic appearance, showed no difference in clinical

behavior from those without calcification in this location. The nature of this unusual calcification anterior to the intervertebral-disc space is uncertain. It probably represents calcification of prevertebral tissues such as the anterior longitudinal ligament. Anterior protrusion of calcified disc material seems an unlikely explanation since the normal height of the disc spaces was maintained.

A majority of the patients showed rapid resolution of the disc calcification following the onset of neck symptoms.

Therapy: Neck traction and analgesics to relieve the local pain and muscle spasm were the usual treatment. These simple procedures, in most cases, resulted in rapid symptomatic improvement.

DISCUSSION

Despite many theories the etiology of this disease remains obscure.

Lyon suggested that these disc calcifications may be the result of metastatic infectious processes. Böhmig, and Coventry and associates described the presence in children of blood vessels connecting the intervertebral discs with the general circulation. These vascular channels, which gradually disappear by the third decade, may expose the intervertebral discs to infectious agents carried in the blood stream. Several patients had signs of infection with fever, sore throat, leukocytosis, and increased sedimentation rate. Other etiological factors, however, must be considered since a majority of these patients had no signs of infection.

Mild or moderate trauma, a common occurrence in childhood, has often been implied as a predisposing factor. Trauma is probably not an important etiological factor, however, since less than a third of the patients gave a history of preceding injury.

Degenerative or vascular disease processes seem unlikely causes in this age group.

Alkaptonuric ochronosis can be ruled out as an etiological factor. It is a generalized metabolic disease which is associated with multiple disc calcifications that do not develop until middle age. Urinary studies for ochronosis were negative in the few children tested.

It has been suggested [12] that this syndrome may be analogous to calcific tendinitis. Disc calcifications had been observed long before the onset of symptoms. Weens reported seeing calcification of the cervical disc seven months prior to the onset of neck symptoms. A similar finding was noted in one of our patients (Case 2) for whom previous spine roentgenograms were available. This patient had had disc calcification two years before the onset of neck symptoms. Similar asymptomatic periods occur in calcific tendinitis, the calcification regressing with activation of the disease. Sandström called attention to the similarity of the nucleus pulposus and the fibrous connective tissue of tendons. We would postulate, therefore, that this disease is related to calcific tendinitis or bursitis and that some unknown factor, possibly trauma or infection, tends to initiate the active symptomatic process. There may then be increased vascularity with subsequent regression of the calcification.

The occasional finding of associated calcification anteriorly, possibly in the anterior ligaments, seems to support this theory and may represent associated calcific ligamentitis of the anterior ligament.

Simple symptomatic therapy such as neck traction and analgesics has been found to be effective. In view of the good prognosis, more radical procedures including roentgen therapy, as advocated by Sandström, do not appear necessary. Two of our patients followed for more than eleven years remained asymptomatic with normal cervical spines on roentgenographic examination. Whether these patients may later develop degenerative changes is not known.

The very rapid disappearance of these calcifications recorded in the literature and noted in our patients may be related to the presence of previously described blood vessels supplying the discs.

SUMMARY

In seven new cases of cervical intervertebral-disc calcification of unknown etiology, all but one patient (Case 4) had an acute episode of pain in the neck, limitation of motion, and torticollis. The similarity to calcific tendinitis is suggested. Trauma or infection may initiate the symptomatic episode. Three of our patients also had calcified material in the prevertebral tissues; this did not alter the favorable prognosis. Very rapid regression of the calcification was noted in most of our patients. This syndrome is probably a much more common entity than the few reports in the literature would suggest.

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Arthrodesis of the Hip with Staple Fixation

BY W. H. KIRKALDY-WILLIS, M.D., F.R.C.S., M. R. CHAUDHRI, M.B., B.S., AND R. J. D. ANDERSON, M.B., B.S., NAIROBI, KENYA

From the Department of Orthopaedic Surgery, King George VI Hospital, and the Orthopaedic Center, Nairobi

In Africa, arthrodesis of the hip, which is often difficult to obtain, is frequently indicated. It is performed far more often than arthroplasty, for it is more important for our patients to be able to walk over rough roads and fields than to be able to sit comfortably at an office desk or in an automobile.

African patients do not stand surgery as well as Europeans. It is therefore vital for orthopaedic surgeons in Africa to have a simple, safe, and speedy method for performing

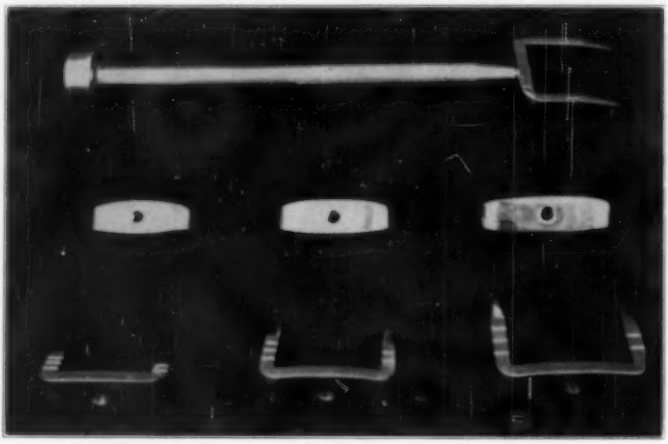

FIG. 1

Introducer and staples.

arthrodesis of the hip. Orthopaedic surgeons must also keep in mind the desirability of maintaining mobility of the knee during the time of immobilization.

METHOD

For the method to be described we acknowledge our great debt to Key, who, in 1926, advised removal of the involved portion of the femoral head, and to Abbott and Fischer who, in 1931, presented a method of hip arthrodesis performed with the patient's limb in wide abduction. We are in complete agreement with the aims, principles, and modifications of the wide-abduction method set down by Abbott and Lucas in their article on this subject in 1954. We have used their method in our clinic for a number of years and have found it to be the most safe and certain means of procuring arthrodesis of the hip in the great majority of cases. We claim that our method, which at first may appear to be slightly new, is actually the logical outcome of work previously done in St. Louis and San Francisco. For the principle of internal fixation of the hip, we are indebted to Osmond-Clarke of the London Hospital. In our method the operation is completed in one stage.

The indications for this method are the same as those advocated by Abbott and Lucas. The surgical approach is also the same. When the hip joint has been opened it will be

FIG. 2-A

Case 8. Chagga girl, four years old, with tuberculosis of the right hip. This preoperative roentgenogram shows almost complete erosion of the femoral head and neck.

FIG. 2-B

Roentgenogram made six months after the arthrodesis. A very small staple was used.

found in some cases that the head and neck of the femur have been almost completely absorbed; in others it will be found that these structures must be removed and, in still others, that good contact between the femoral head and the acetabulum can be obtained by denuding these structures of cartilage and by shaping them until perfect apposition between the femoral head and upper part of the acetabulum has been obtained. Whatever the condition of these structures, it is possible, with a little ingenuity, to obtain their good apposition in the desired position. Equalization of limb length is highly desirable in Africa, where so many people do not wear shoes. Equalization can be obtained by placing the affected limb in a position of slight abduction, which does not appear to be attended by any serious disadvantages.

FIG. 3-A

Case 35. Preoperative roentgenogram of a Kikuyu man, twenty years old, with tuberculosis of the right hip.

FIG. 3-B

Roentgenogram made one year after the arthrodesis, showing complete fusion.

When the femoral head has been replaced in the acetabulum in the correct position, the hip joint is immobilized internally by the insertion of a large staple. This staple is made in three sizes and has a short portion that fits into the ilium medial to the anterior spine, and a long portion that fits into the femoral neck or the trochanteric region (Fig. 1). The staple is inserted by means of an introducer into which it is screwed. It is held by this introducer while it is hammered into the bone in the correct position, following which the introducer is unscrewed. The anterior portion of the iliac crest is removed and cut into

small chips. These are placed, under pressure, between the femoral head and the acetabulum, both above and below the joint, and act as a contact-compression agent as well as an osteogenetic agent. When the staple described above is used to maintain apposition and to secure internal fixation, it is rarely necessary to place the limb in wide abduction. The desired position of the limb can be obtained at operation, and there is, therefore, no need for a second operation in which osteotomy of the femoral shaft is performed in order to obtain adduction.

The wound is sutured in layers, and a double hip plaster spica is applied and maintained for three months. The portion of the cast below the knee is bivalved so that the posterior portion can be removed daily in order to permit flexion of the knee under the supervision of a physical therapist. In the majority of cases there is firm bone fusion at the end of three months. In cases of tuberculosis of the hip we use a short single spica for a longer period; this apparatus is easier to make than a molded leather support.

PRINCIPLES

The principles involved in this procedure are:

1. Good apposition is obtained between the denuded cancellous bone of the acetabulum and that of the femoral head and trochanteric region.

2. Complete immobilization of the joint is obtained by means of a staple placed internally and a plaster spica applied externally.

3. Osteogenesis is stimulated by the insertion of cancellous-chip grafts obtained from the iliac crest. These chips are wedged into all the spaces around and between the bones following staple fixation and act as a contact-compression agent, producing the same effect as does the pull of the adductor muscles following arthrodesis with the limb in wide abduction.

4. Early mobilization of the knee joint is secured in order to prevent stiffness.

RESULTS

We have treated thirty-seven patients with hip disease by this method during the last five years (Table I). In twenty of these cases the roentgenograms provided incontrovertible evidence of complete bone fusion. In another three cases (Cases 13, 28, and 34) the roentgenograms showed marked trabecular shadows passing across the site of the original joint. In fifteen cases, the clinical tests showed definite fusion but the evidence of the roentgenograms was not completely indicative of bone fusion. These fifteen cases included the three cases in which the roentgenograms showed trabeculae across the joint. In one case (Case 20), the fusion appeared doubtful, both clinically and roentgenographically; in this case the greater trochanter and the head and neck of the femur had been destroyed. In another case (Case 9), the results of the clinical tests were positive, but there was no evidence of fusion in the roentgenograms, making it doubtful that real fusion was present.

In most cases fusion was present by three months after the operation. In two cases, however, fusion was slightly delayed but was firm by four months (Case 15) and seven months (Case 36) after the operation. In one of the thirty-seven cases (Case 27), an adduction deformity of 10 degrees developed over a period of a year.

ADVANTAGES OF THIS METHOD

1. It can be seen in Table I that this method is a relatively certain means of procuring firm arthrodesis of the hip by three months after the operation.

2. In African patients, who tolerate major surgery poorly, it has proved to be the safest method. Trumble's method is not as certain and causes much more shock to the patient.

3. It is a one-stage operation which allows early mobilization of the knee.

TABLE I

Case No.	Age (*Years*)	Sex	Tribe or Race	Hip	Preoperative Condition	Time at Which Fusion Was Present	Range of Knee Flexion	Final Limb-Length Discrepancy	Length of Follow-Up	Final Result
1	30	M	Marigoli	L	Osteo-arthritis; 1½ in. shortening	3 mos.	Full	½ in. short	4 yrs.	X-ray evidence of fusion
2*	35	M	M'Kamba	R	Tuberculosis	3 mos.	Full	None	4 yrs.	X-ray evidence of fusion
3	12	M	Kikuyu	L	Legg-Perthes disease; ¼ in. shortening	3 mos.	Full	1¾ in. short	1 yr.	X-ray evidence of fusion
4*	29	M	M'Kamba	R	Osteo-arthritis	3 mos.	70° at 6 mos.		1 yr.	X-ray evidence of fusion
5	15	F	Meru	R	Poliomyelitis; 1 in. shortening	2½ mos.		1½ in. short	1 yr.	X-ray evidence of fusion
6	17	M	Kikuyu	R	Legg-Perthes disease	3 mos.	Full	None	4 yrs.	X-ray evidence of fusion
7	35	F	Masai	R	Infectious arthritis	3 mos.			10 mos.	X-ray evidence of almost complete fusion; clinical evidence of complete fusion
8	4	F	Chagga	R	Tuberculosis	3 mos.			1 yr.	X-ray evidence of fusion
9	8	M	Kikuyu	L	Tuberculosis	3 mos.	90° at 6 mos.	½ in. short	2 yrs.	Clinical evidence of fusion; x-rays showed no evidence of bone fusion
10	8	F	Kikuyu	L	Tuberculosis	3 mos.	Full at 6 mos.	½ in. short	6 mos.	Clinical evidence of fusion
11	4½	M	Kikuyu	L	Tuberculosis; 1½ in. shortening	3 mos.	90° at 3 mos.	None	1 yr.	X-ray evidence of fusion
12	32	M	Jaluo	R	Unreduced dislocation; ½ in. shortening	3 mos.	100° at 5 mos.		1½ yrs.	X-ray evidence of fusion
13	30	F	Kipsigis	R	Brucellosis	3 mos.	100° at 3 mos.	None	1 yr.	X-ray evidence of fusion
14	55	F	Kikuyu	L	Unreduced dislocation; 2 in. shortening	3 mos.	60° at 3 mos.	½ in. short	7 mos.	Clinical evidence of fusion; x-rays showed trabeculae across joint
15		F	Kenya	L	Unreduced dislocation	4 mos.			9 mos.	Clinical evidence of fusion
16	25	M	M'Kamba	R	Tuberculosis	3 mos.	90° at 3 mos.	½ in. short	2 yrs.	X-ray evidence of fusion
17	45	M	European	L	Infectious arthritis	3 mos.	30°	½ in. short	1½ yrs.	X-ray evidence of fusion
18	40	M	European	R	Unreduced dislocation	3 mos.	35° at 3 mos.		1 yr.	Clinical evidence of fusion

19	13	F	European	R	Tuberculosis	3 mos.	Full at 6 mos.	¾ in. short	1 yr.	X-ray evidence of fusion
20	20	F	Asian	R	Congenital dislocation				6 mos.	Staple misplaced; x-ray and clinical evidence indicate fusion doubtful
21	16	F	Muganda	R	Unreduced pathological dislocation; arthritis	3 mos.			6 mos.	Clinical evidence of fusion
22	40	M	African		Unreduced dislocation; arthritis	3 mos.	45° at 3 mos.		6 mos.	Clinical evidence of fusion
23	18	F	Asian	R	Tuberculosis	3 mos.	55° at 3 mos.		6 mos.	Clinical evidence of fusion
24*	24	M	Asian	R	Poliomyelitis	3 mos.			10 mos.	Clinical evidence of fusion; x-ray evidence inconclusive; hip stable
25*	31	M	Kikuyu	R	Tuberculosis	3 mos.	35°	½ in. short	5 yrs.	X-ray evidence of fusion
26	13	M	Kikuyu	R	Legg-Perthes disease	3 mos.	Full at 6 mos.	½ in. short	2 yrs.	X-ray evidence of fusion
27	25	M	Kikuyu	L	Osteo-arthritis	3 mos.	Full at 6 mos.	1½ in. short	3½ yrs.	X-ray evidence of fusion
28	8	F	Luo	L	Tuberculosis	3 mos.	Full at 6 mos.	½ in. long	9 mos.	Clinical evidence of fusion; x-rays showed trabeculae across joint
29	8	M	Kikuyu	R	Infectious arthritis	3 mos.	Full at 6 mos.	1½ in. short	2½ yrs.	X-ray evidence of fusion
30	25	M	Myanza	L	Tuberculosis	3 mos.	Full	½ in. long	1 yr.	X-ray evidence of fusion
31	26	M	Kikuyu	L	Tuberculosis	3 mos.	90° at 4 mos.	None	1½ yrs.	X-ray evidence of fusion
32	30	M	Kikuyu	L	Tuberculosis	3 mos.	90° at 6 mos.	½ in. short	1½ yrs.	Clinical evidence of fusion; x-rays not available
33	15	M	Kikuyu	L	Osteo-arthritis	3 mos.	Full at 3 mos.	½ in. short	1 yr.	Clinical evidence of fusion; x-rays not available
34	25	M	Muluhia	L	Unreduced dislocation	3 mos.	Full at 6 mos.	None	9 mos.	Clinical evidence of fusion; x-rays showed trabeculae across joint
35	20	M	Kikuyu	R	Tuberculosis	3 mos.	Full at 6 mos.	1½ in. short	1 yr.	X-ray evidence of fusion
36	7	M	Luo	R	Tuberculosis	7 mos.	90° at 8 mos.	1¼ in. short	1 yr.	Clinical evidence of fusion; x-ray evidence inconclusive
37	15	M	Masai	L	Tuberculosis	3 mos.	90° at 3 mos.		19 mos.	Clinical evidence of fusion; x-rays showed no trabeculae across joint

* Ischiofemoral instead of intra-articular arthrodesis was done.

These three reasons explain why we prefer our method to the abduction method. We believe that the results are equally satisfactory.

Chemotherapy has made the use of internal fixation a safe procedure. In only one patient in our series was it necessary to remove the staple; and in no patient with tuberculosis did the use of metal have any harmful effect or was it necessary later to remove the staple.

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DISCUSSION

Central Fractures of the Acetabulum

(Continued from page 60)

For several years we have used stereoscopic views routinely in the roentgenographic examination of the pelvis. An oblique view may be obtained by using a grid cassette or, if it is possible to roll the patient 25 or 30 degrees, oblique stereoscopic roentgenograms may be made. It is then possible to obtain a broad view of the lateral wall of the true pelvis.

We have had seven patients on whom open operative procedures were done between two and six years ago. In four of these excellent results were obtained; in two the result was fair and one, poor. The one patient with a poor result had a very comminuted fracture in which complete reduction could not be obtained. In the two patients with fair results, there was upward impaction of the acetabulum so that the outlook in the beginning was not good. With our present understanding of these severe joint fractures, we might have done a better job by attempting to restore the dome fragment.

An anterior approach has been used in all of our patients, with a second procedure being done on one patient through a posterior incision. In the vertical fractures with a saggital plane, it is usually possible to obtain reduction by inserting a retractor beneath the iliacus and applying strong lateral traction against the medially displaced fragment in the lateral wall of the true pelvis. Fixation screws are inserted through a stable portion of the ilium above the acetabulum with the tips of the screws extending through the loose fragment. Traction must be maintained during and following the operative procedure.

I certainly agree that reduction of these fractures is urgent. Serious permanent hip disability frequently can be prevented.

Central (Medullary) Fibrosarcoma of Bone*

BY W. SCOTT GILMER, JR., M.D., AND G. DEAN MACEWEN, M.D., MEMPHIS, TENNESSEE

From the Campbell Clinic and the Department of Pathology and Microbiology, University of Tennessee Medical Units, Memphis

In reviewing all cases of malignant tumors involving bone recorded at the Campbell Clinic from 1930 through 1955, we were able to classify histologically 227 as primary tumors of bone. Of this group, twenty-two, or 9.7 per cent, were identified as central or medullary fibrosarcoma.

We were not able to gain from the literature any firm conclusions concerning the prognostic implications of such a diagnosis, since this specific group of tumors was not discussed in detail but only by reference to pertinent cases in general reviews. Usually this type of tumor is classified with bone-forming sarcoma (frequently as "osteolytic-

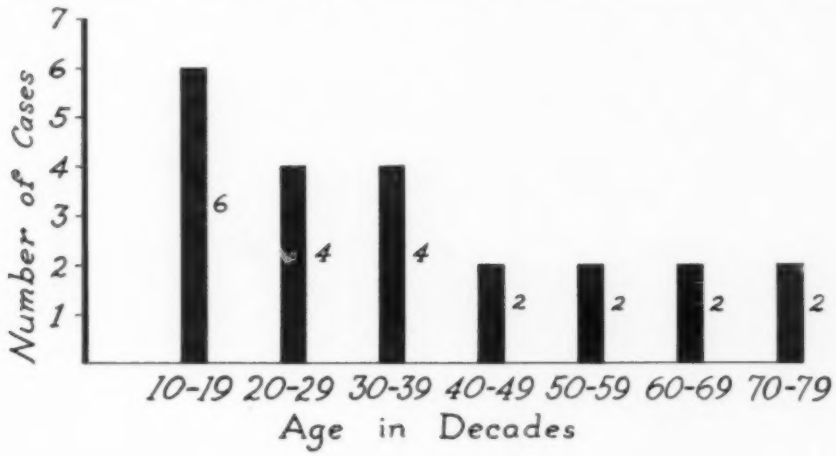

CHART I

Distribution of Patients by Decades.

osteogenic sarcoma") or with fibrosarcoma of parosteal origin. Therefore, we felt that a detailed analysis of the tumors in our series would be of some general worth.

Differentiation of these tumors from those of periosteal or parosteal origin was made readily by means of the location of the main mass of tumor in the marrow cavity. Those cases in which the origin of the tumor might have been extra-osseous were not included in the series.

Table I is a review of certain pertinent data of all cases. All cases could be analyzed for age and sex of patient, location of the lesion, roentgenographic findings, and histological grading. However, only twenty-one patients were followed adequately, and two of these were eliminated, for reasons which will become evident.

ANALYSIS OF CASES

Age and Sex of Patients

Chart I shows the distribution of patients in each decade in the age ranges of from

* Aided in part by Grant #A1073 (C), National Institutes of Health, United States Public Health Service, Department of Health, Education, and Welfare.

TABLE I

SUMMARY OF CASES

Case	Age (*Years*)	Sex	Symptoms	Duration of Symptoms until Therapy (*Months*)	Location of Lesion	Grade	Therapy	Follow-up
1	35	F	Pain; palpable mass	6	Proximal metaphysis of tibia	II	Supracondylar amputation; x-ray therapy	Died with pulmonary metastases 31 months after therapy
2	21	M	Pain; palpable mass	10	Proximal metaphysis of tibia	II	High-thigh amputation	Died with pulmonary metastases 3 months after therapy
3	30	M	Pain	12	Distal metaphysis of femur	II	High-thigh amputation; Coley's toxin	Died with pulmonary metastases 61 months after therapy
4	16	M	Pain; palpable mass	3	Proximal metaphysis and diaphysis of tibia	II	Supracondylar amputation; Coley's toxin	Alive and well 25 years after therapy
5	20	M	Pain; palpable mass	12	Proximal metaphysis of tibia	I	Curettement; packing with bone chips	Alive and well 23 years after therapy
6	16	M	Pain	9	Distal metaphysis of femur	II	Hip disarticulation; Coley's toxin	Alive and well 22 years after therapy
7	12	M	Pain; palpable mass	5	Distal metaphysis of femur	III	High-thigh amputation	Died with pulmonary metastases 7 months after therapy
8	37	M	Pain; palpable mass	24	Distal metaphysis of femur	I	High-thigh amputation	Alive and well 20 years after therapy
9	24	F	Pain; palpable mass	12	Distal metaphysis of femur	II	Hip disarticulation	Died with pulmonary metastases 4 months after therapy
10	67	M	Pain; palpable mass; pathological fracture	3	Proximal two-thirds of shaft of humerus	III	No therapy; patient had pulmonary metastases when first seen	Died 3 months after biopsy

11	18	F	Pain; palpable mass	8	Distal metaphysis of femur	III	High-thigh amputation	Died with pulmonary metastases 8 months after therapy
12	19	F	Pain; pathological fracture	12	Neck of femur	III	X-ray therapy	Died with pulmonary metastases 4 months after therapy
13	39	M	Pain	6	Distal metaphysis of femur	II	Mid-thigh amputation	Alive and well 15 years after therapy
14	73	F	Pain; pathological fracture	12	Neck of femur	III	X-ray therapy	No follow-up
15	58	M	Pain	14	Neck of femur	II	Hip disarticulation; x-ray therapy	Died with pulmonary metastases and local recurrence in stump 17 months after therapy
16	42	F	Pain	8	Distal metaphysis of femur	II	No therapy; patient had pulmonary metastases when first seen	Died 5 months after biopsy
17	61	F	Pain; palpable mass	6	Distal metaphysis of femur	II	High-thigh amputation	Died with pulmonary and liver metastases 18 months after therapy
18	28	M	Pathological fracture	No delay	Proximal metaphysis of tibia	II	Mid-thigh amputation	Died 8 months after therapy
19	16	M	Pain; palpable mass	4	Proximal metaphysis of tibia	II	Hip disarticulation	Died with pulmonary metastases 26 months after therapy
20	72	M	Pain; pathological fracture	31	Shaft of femur	I	High-thigh amputation	Died with pulmonary embolism 4 days after therapy
21	47	M	Pain; palpable mass	6	Tibial plateau	II	Mid-thigh amputation	Died with pulmonary metastases 8 months after therapy
22	50	M	Pain; palpable mass	6	Distal metaphysis of femur	II	Hip disarticulation	Alive and well 19 months after therapy

twelve to seventy-three years. The majority were in the second, third, and fourth decades of life. The median age was thirty-three years. Fifteen were males and seven were females.

Location of Lesions

Ten lesions were in the distal portion of the femur, seven in the proximal portion of the tibia, three in the proximal portion of the femur, one in the shaft of the femur, and one involved the upper two-thirds of the humerus. Therefore, 45 per cent involved the distal portion of the femur and 32 per cent the proximal portion of the tibia. Thus 77 per cent of the lesions occurred near the knee joint.

FIG. 1

Case 17. Anteroposterior roentgenogram made November 1, 1947 and lateral roentgenogram made November 12, 1947, showing the irregular lytic character of the lesion in the distal femoral diaphysis and metaphysis, and demonstrating the moderate periosteal reaction.

Symptoms

Three cardinal symptoms were considered: pain, palpable mass, and pathological fracture.

Twenty-one patients complained of pain of three to twenty-four months' duration, an average of eight months. Thirteen were conscious of a mass for from two to twelve months before seeking aid, an average of five and one-half months.

Five patients had a pathological fracture at first examination. In one (Case 18), there were no prior symptoms, although a benign lesion in the same area had been treated with irradiation eleven years previously. Three of the fractures involved the shaft of a long bone, two the neck of the femur.

Interval Prior to Consulting Physician

Patients hesitated for from one to twelve months after the onset of symptoms before consulting a physician, with an average time lapse of five months. In Case 8 symptoms dated from a fracture twenty-four months prior to the patient's being seen, but evalua-

tion of the bone status at the time of that injury was not possible. One patient who was seen immediately after a pathological fracture had had no previous symptoms.

Interval Prior to Institution of Therapy

Two patients (Cases 10 and 16) had multiple pulmonary metastases when first seen, so only palliative therapy was offered. Ten patients received definitive therapy within a matter of days. In the remainder there were intervals of one to nineteen months, with an average of five months.

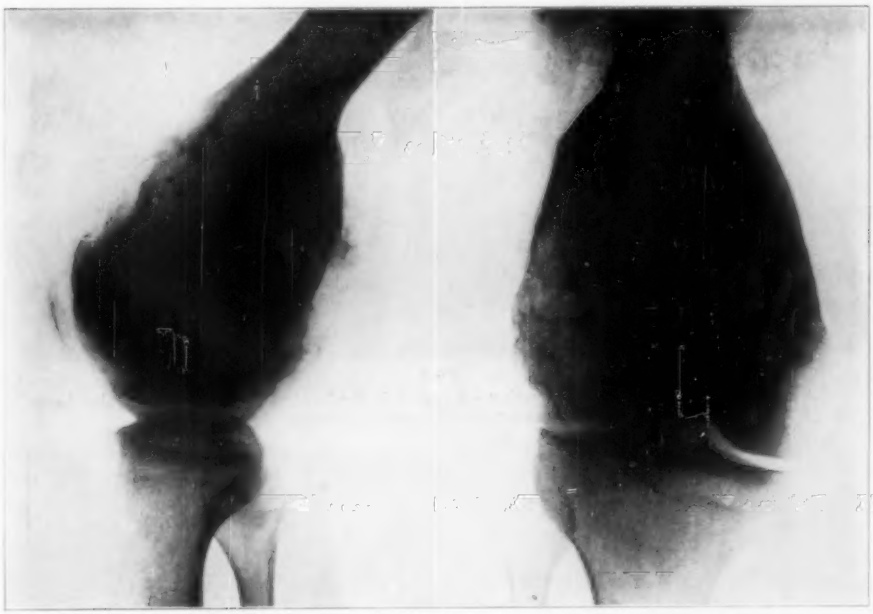

FIG. 2

Case 13. Roentgenograms showing the expansion of the lower portion of the femur with patchy sclerosis and trabeculation produced by the lesion.

Type of Therapy

Seventeen patients underwent amputation or disarticulation. In only one (Case 15) was there a local recurrence. Two patients received irradiation in addition to amputation, three Coley's toxin in addition to amputation, two irradiation alone, and one curettage alone.

Roentgenographic Findings

Characteristically, the lesions were lytic with irregular, indefinite, "moth-eaten" margins (Fig. 1). Marginal sclerosis as well as expansion of bone was seen only in the lower grade tumors, which in some instances were trabeculated (Fig. 2). Destruction of the cortex was not uncommon in the more aggressive tumors (Fig. 3). Vague to well defined patchy sclerosis was observed and periosteal reaction was frequent but never marked (Figs. 1 and 4). Frequently, study of the roentgenogram did not indicate the extent of the involvement of bone by tumor (Figs. 6, 9, and 10).

Periosteal reaction was commoner in the more aggressive tumors but never was of great magnitude. In the lower grade tumor, expansion and thinning of the cortex, both with and without focal areas of destruction was common.

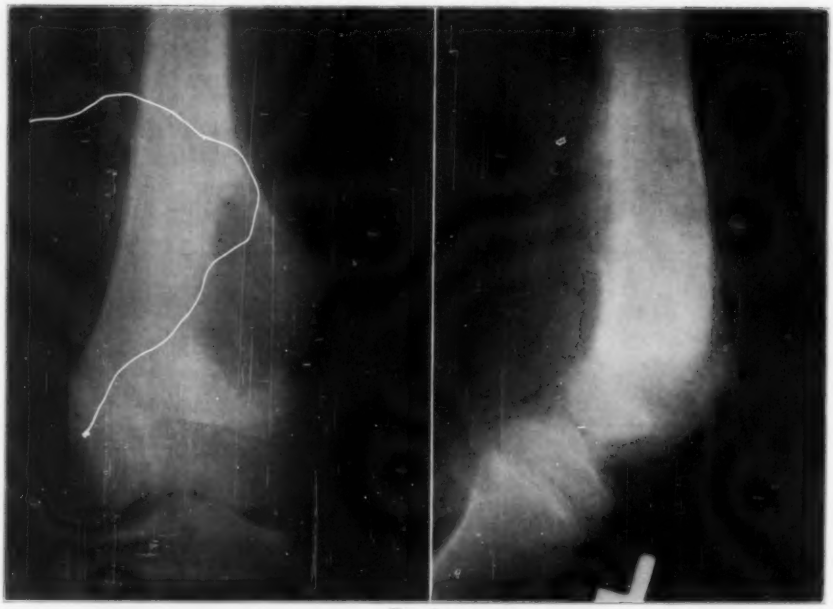

FIG. 3

Case 7. Roentgenograms demonstrating an eccentrically located lesion with irregular bony margins, cortical destruction, and considerable periosteal reaction.

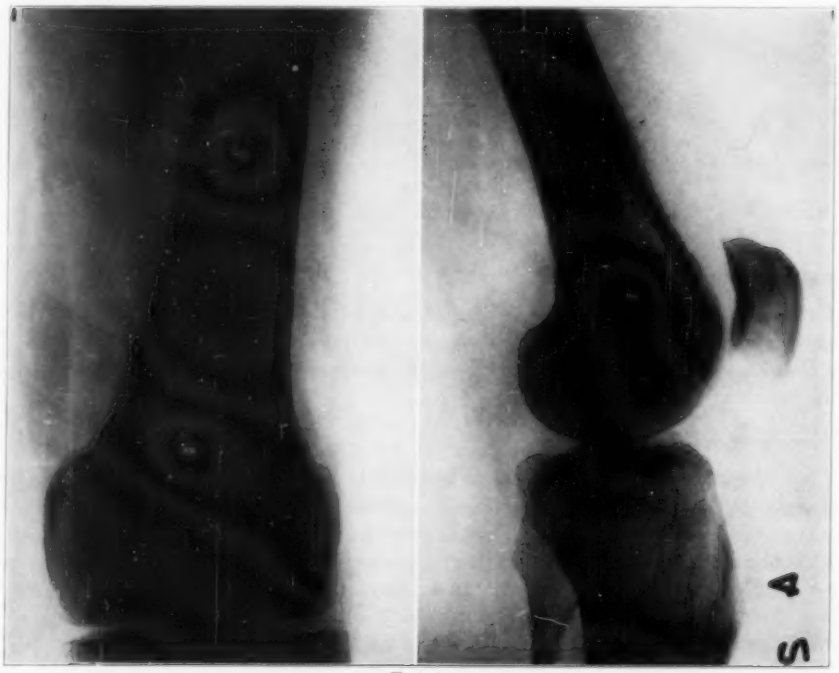

FIG. 4

Case 22. Roentgenograms showing the fibrosarcoma, located entirely within the medullary canal, with the sharply defined margin and minimal periosteal reaction of the less aggressive tumors.

FIG. 5

Case 21. Roentgenograms showing only minimal irregular ill defined destruction of the lateral tibial condyle.

The involvement of bone was centered about the metaphysis, but epiphyseal and diaphyseal involvement was common. Pathological fractures were not common (22 per cent), probably because shaft involvement was rare.

Gross Appearance of Tumors

The tumors were fleshy, rubbery, and gray-white or pinkish. Marked vascularity was not observed; necrosis was unusual and never extensive. Destruction of the cortex was fairly frequent (Figs. 3 and 7), but many of the tumors were confined to the medullary canal (Figs. 9 and 10), necessitating windowing of the cortex to obtain tissue for examination. Although extra-osseous extension was observed, in no instance did it approach the magnitude of the medullary portion of the tumor.

Histological Study

When the interosseous origin and malignant character of a specific tumor had been established, it was necessary to identify the exact nature of the neoplasm and to classify it accordingly. Since we were concerned only with fibroblastic tumors, it was essential to search carefully for evidence of the formation of cartilage or for osteoid material and bone produced directly from, or through the mediation of, tumor cells without cartilaginous intermediary.

The elimination of malignant cartilage-forming tumors was not a problem in the cases under consideration. However, having recently studied a case of tumor of the ilium, clearly a chondrosarcoma at the time of original excision, which recurred as a fibrosarcoma and shortly metastasized as an osteogenic sarcoma, we have become increasingly aware of the multiple potentialities of primitive mesenchymal tumors, and have exercised great caution in classifying them. To eliminate tumors in which bone and osteoid production is an identifying or classifying feature is not, in general, a great problem. However, it is well known that such tumors may be almost purely fibroblastic in some areas. This was

FIG. 6

FIG. 7

Fig. 6: Case 21. Photograph of hemisection of a gross specimen, showing the true extent of the tumor, not revealed in the roentgenogram.

Fig. 7: Case 7. Photograph of hemisection of a gross specimen, demonstrating the cortical destruction in the metaphysis as well as the periosteal reaction seen in the roentgenogram.

true in our experience, especially in those areas of extra-osseous extension of such tumors. We were fortunate in having the gross specimens available for study from eleven of the patients and fixed tissue from all but three of the remainder, including one specimen obtained at autopsy. Consequently, we were able to sample each tumor adequately, and thus feel that all reasonable care was exercised to exclude tumors which were not of a purely fibroblastic nature. Therefore, we feel that the placing of the tumors under consideration in a separate group is justified.

An attempt was made to evaluate the degree of activity of the lesion according to several factors: cellularity, pleomorphism, mitotic activity, amount of stroma, degree of fascicular arrangement, and vascularity. Of these, the first four seemed most important.

With the use of these criteria, tumors were graded I, II, and III. There were three Grade I, fourteen Grade II, and five Grade III tumors. Grade I tumors had little pleomorphism, considerable collagen, rare mitotic activity, and, in some instances, definite fascicular arrangement (Fig. 11). Grade III tumors showed moderate to marked pleomorphism, little stroma (almost none at times) and in them mitosis was conspicuous, at times taking place in twelve to fifteen cells per high power field (Fig. 12). Organoid pattern or fascicular arrangement of cells was not seen. Grade II tumors were intermediate in character (Fig. 13).

Hemosiderin deposition and accumulations of fat-laden macrophages, so common in benign fibrous-tissue lesions of bone, were extremely rare and inconspicuous, and were seen only in the least aggressive tumors.

Three cases require additional comment. A tumor (Case 15) in the upper portion of the femur, which we placed in the Grade II category because of the histological picture

FIG. 8

FIG. 9

FIG. 10

Fig. 8: Case 6. Drawing of a gross specimen illustrating cortical destruction although the tumor is almost entirely confined to the medullary canal.

Fig. 9: Case 17. Photograph of a gross specimen, showing the tumor in the lower portion of the femur confined to the medullary canal in the metaphysis and diaphysis. The tumor is more extensive than the roentgenogram indicated.

Fig. 10: Case 22. Photograph of a gross specimen, illustrating the tumor confined to the medullary canal in the metaphysis. The hemorrhagic appearance is due to the trauma incident to biopsy. The tumor is more extensive than the roentgenogram indicated.

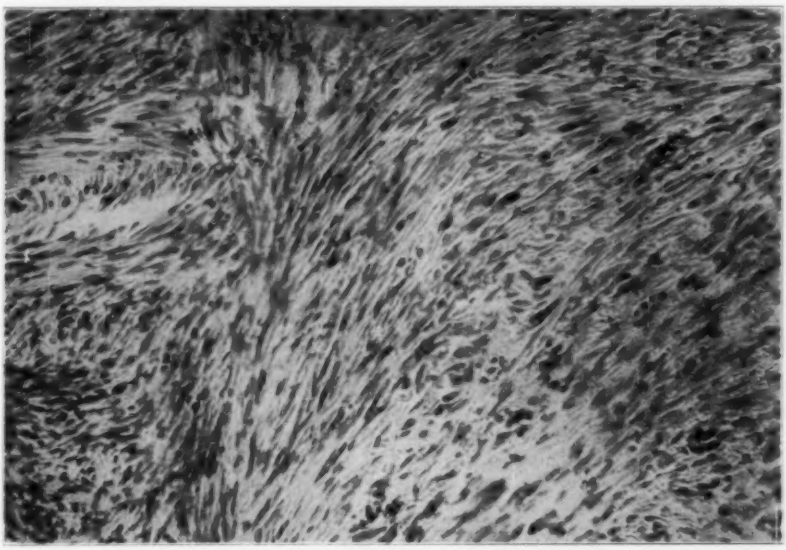

FIG. 11

Case 8. Photomicrograph showing a Grade I fibrosarcoma. There is a distinct fascicular arrangement of the tumor cells with defined polarity and little pleomorphism. Intercellular collagen is abundant. A single mitotic figure is seen.

of the second recurrence following hip disarticulation (Fig. 14), originally was diagnosed as a benign lesion, in which diagnosis we concurred after studying the original material (Fig. 15). The most reasonable diagnosis here is non-osteogenic fibroma. In the first recurrence following curettage, however, the picture altered considerably, both roentgenographically and histologically (Figs. 16-A through 17). The second recurrence and death followed rapidly.

There are two possible interpretations: first, that the original tissue studies were not adequate; second, that this case represents the transformation of a non-osteogenic fibroma into a fibrosarcoma, an occurrence not previously observed so far as we are aware.

The second case of possibly unusual nature is Case 5 in which the patient was treated

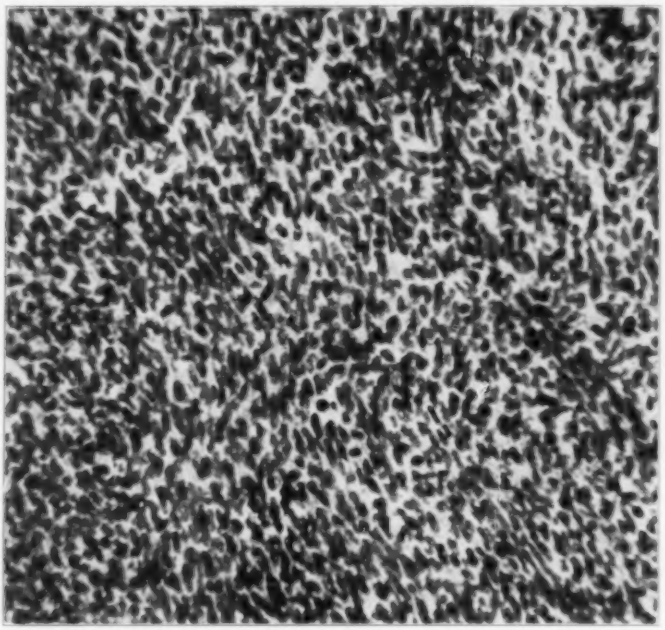

FIG. 12

Case 7. Photomicrograph showing a Grade III fibrosarcoma. There is a marked cellularity with scant intercellular collagen and considerable cellular pleomorphism. Mitotic figures are conspicuous.

with curettage alone. While we feel that unquestionably a diagnosis of fibrosarcoma, Grade I is justified, the fact that curettage alone resulted in a cure is unusual. The effect of severe wound infection and subsequent osteomyelitis upon any residual tumor is an interesting problem.

The third case is Case 18 in which the patient received irradiation therapy for a benign soft-tissue lesion eleven years prior to being seen with a Grade II fibrosarcoma in the tibia at the same site. In all probability this is an irradiation-induced sarcoma.

CASE HISTORIES

CASE 1. S.W.Mc., a white woman, thirty-five years old, was first seen six months after the onset of pain over the inner aspect of the upper portion of the left tibia. Physical examination revealed a slight swelling of the upper portion of left tibia just medial to the tuberosity. Roentgenographic examination disclosed an irregular lytic lesion involving the upper third of the left tibia. The cortex was thin and there was a minimal periosteal reaction. The medullary canal was curetted through a trap-door incision on the medial aspect of the upper portion of the tibia. Microscopic examination of the specimen disclosed a moderately cellular tumor of spindle-shaped cells with vesicular nuclei. There was little pleomorphism, only scattered

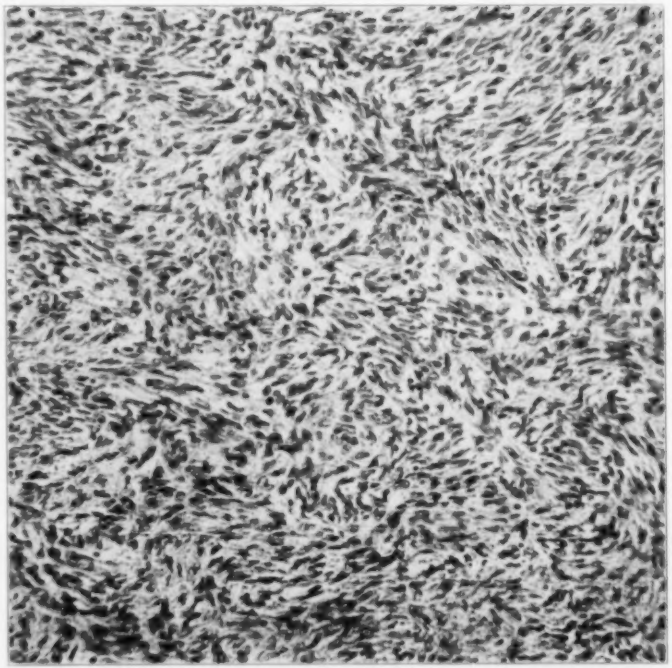

FIG. 13

Case 22. Photomicrograph showing a Grade II fibrosarcoma. There is a well defined fascicular pattern and a moderate amount of intercellular collagen. Pleomorphism is not pronounced.

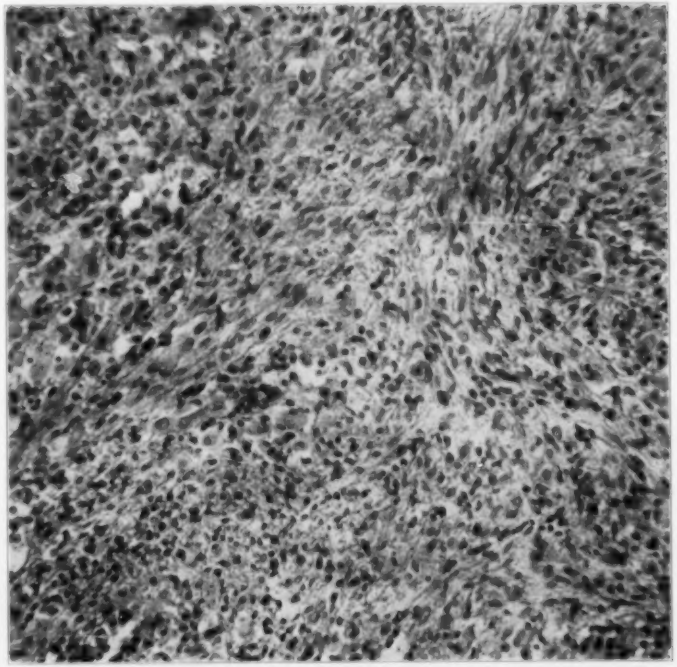

FIG. 14

Case 15. Photomicrograph of a specimen of the tumor in the upper portion of the femur. This was the second recurrence of tumor in this location.

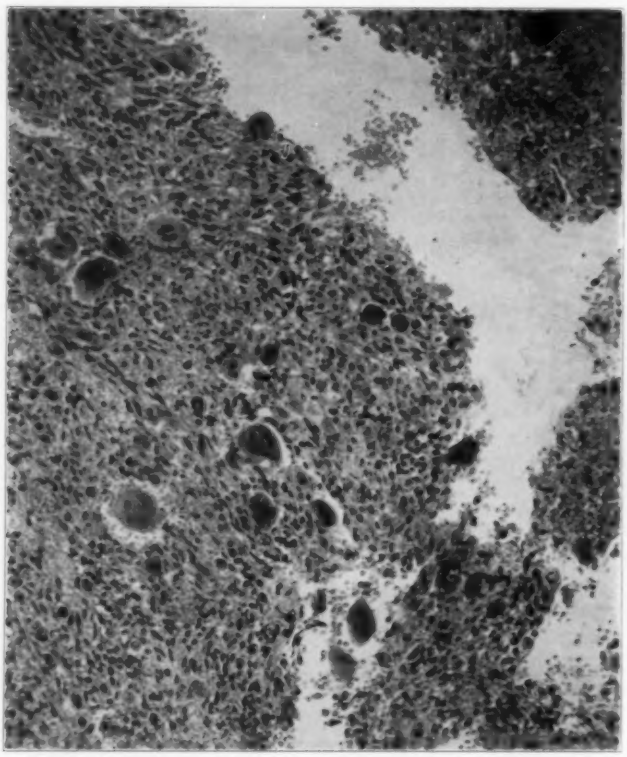

FIG. 15

Case 15. Photomicrograph of a specimen of the original lesion which was interpreted as benign.

mitotic figures and a moderate amount of collagen formation. There was a good fascicular arrangement. An above-the-knee amputation was done. Gross examination of the specimen disclosed a soft, blue-white translucent tissue occupying the upper one-third of the medullary canal of the tibia. The cortex was intact.

CASE 2. L.H.J., a white man, twenty-one years old, was first seen ten months after the onset of pain following a minor injury to the right knee. Three months following this initial injury, the patient had been operated upon. The medial meniscus was removed and the joint explored. Subsequently swelling and a flexion contracture developed. Physical examination revealed a marked swelling of the right knee without effusion or localized mass. Roentgenographic examination disclosed an irregularly destructive lesion in the medial portion of the proximal metaphysis of the tibia with considerable sclerosis above and lateral to it. This destruction occupied an area beginning one centimeter from the articular surface and extending downward for nine centimeters. On the medial aspect of the tibia the cortex was broken through at about the junction of the metaphysis and diaphysis. Biopsy was done and a gray-white homogeneous tumor was found arising from the tibia and extending upward. An above-the-knee amputation was done. Examination of the gross specimen revealed a gray-white semitranslucent tumor with areas of mucinous change involving seven centimeters of the upper diaphysis and metaphysis of the tibia, then eroding the cortex and extending upward to the posterior compartment of the knee joint. Microscopically, the tumor was fairly cellular, the cells oval and spindle-shaped, arranged in parallel bundles for the most part, but in some areas, rather irregularly disposed. Mitosis was present with moderate frequency and here and there were dense areas of hyalinization, some of which were calcified.

CASE 3. E.C. was a thirty-year-old white man who was first seen one year after development of pain with some loss of muscle power in the left lower limb. Physical examination revealed tenderness over the lateral condyle of the femur and also some fullness in the popliteal surface. Roentgenographic examination disclosed an irregular, lytic, somewhat mottled or trabeculated lesion involving the lateral femoral condyle,

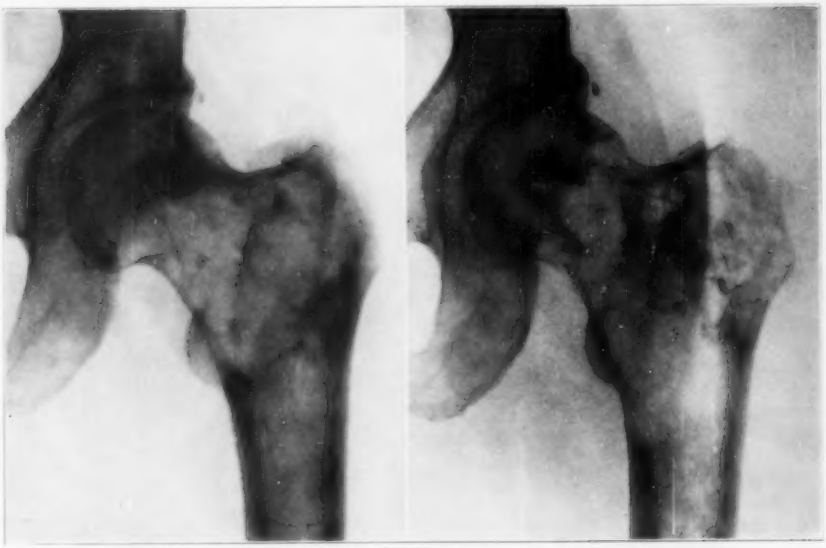

FIG. 16-A

FIG. 16-B

Figs. 16-A, 16-B, and 16-C: Case 15. Serial roentgenograms made April 4, 1945, September 9, 1945, and November 22, 1945. On the left, the lesion is that seen at the time of the original biopsy, and on the right, that at the time of the development of a pathological fracture immediately before the hip was disarticulated.

FIG. 16-C

extending into the metaphysis as well as posteriorly to the cortex above the condyles. The cortex was expanded anteriorly and laterally, and while greatly thinned out, was intact. Tissue was removed through a window made in the lateral condyle and metaphysis of the lower portion of the femur. A high-thigh amputation was then done. On gross study the tumor tissue was found to be blue-white, translucent, and rubbery. It involved both condyles, extending to within one-half centimeter of the intercondylar fossa, and up the shaft of the femur for twelve centimeters. The cortex was intact except for the area removed surgically.

CASE 4. B.H., a sixteen-year-old white boy was seen three months after the onset of pain in the region of the left knee. There was a slight firm swelling over the upper end of the left tibia. Roentgenographic examination revealed an irregular, mottled destructive lesion with focal calcifications, involving the metaphysis of the upper portion of the tibia. There was a moderate periosteal reaction but the cortex was intact in all views. A biopsy was done and a markedly thickened periosteum encountered, a portion of which was removed. Subsequently, an amputation was performed. Examination of the gross specimen disclosed tumor tissue occupying the medullary canal of the tibia from the proximal epiphyseal plate downward, for thirteen centimeters. In the upper metaphysis there was some peripheral sclerosis, and the periosteum was thickened, obviously due to infiltration of tumor. The cortex was intact. Microscopically, this was a fairly cellular tumor composed of oval and fusiform cells with moderate amounts of cytoplasm and vesicular nuclei, a fair degree of pleomorphism with an area of multinuclear giant-cell formation and some tumor giant

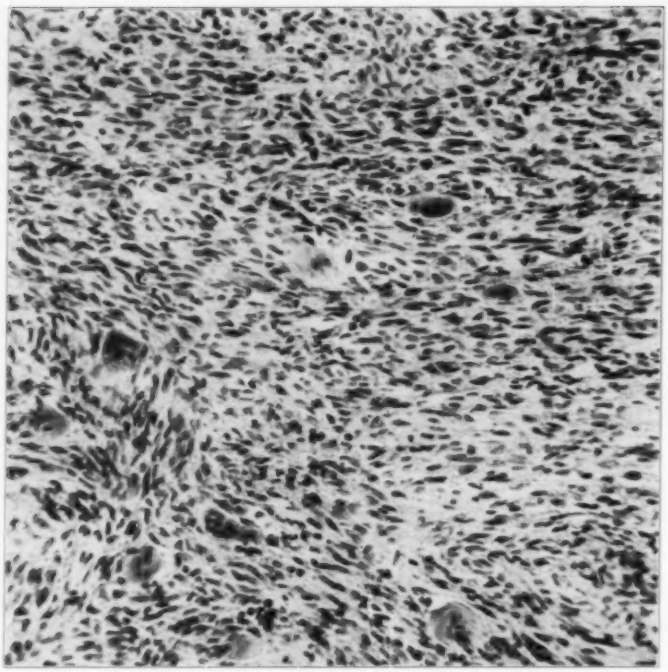

FIG. 17

Case 15. Photomicrograph of a specimen of the lesion taken at biopsy at the time of the first recurrence.

cells as well. There was fascicular arrangement of the cells, and in a moderate number of them mitosis was taking place. In some areas, there was a moderate amount of intercellular collagen.

CASE 5. Z.J. was a twenty-year-old white man who was first seen with a complaint of pain over the upper portion of the left tibia of one year's duration, followed by the development of a mass which grew for two months, then ceased. Seven months prior to admission the mass was incised and clotted blood removed. Physical examination revealed expansion of the condylar region of the left tibia with a bone mass apparently arising from the medial condyle and extending backward into the popliteal space. Roentgenographic examination revealed an expansile lytic trabeculated lesion occupying the upper one-fourth of the tibia with the cortex greatly expanded, particularly posteriorly and medially and markedly thinned, but intact over the entire tumor. There was considerable sclerosis in the medullary canal distal to the tumor. An opening was made in the thinned cortex over the mass and a thick fibrous tissue surrounding a central cavity filled with a brown, semiliquid material was encountered. All of the material was carefully curetted and the wound was filled with bone chips. Grossly, the material was gray-yellow or blood stained and rather fibrous, containing here and there granular calcareous masses. Microscopically, the material was composed, in part, of granulation tissue in which there were spicules of reactive bone. Elsewhere, it was a moderately cellular tumor composed of oval and fusiform fibroblastic types of cells, fairly closely packed in a fascicular arrangement. Mitotic figures were rare and there was considerable intercellular collagenic material. In some areas giant cells of the foreign-body type were seen.

CASE 6. R.C. was a sixteen-year-old white boy seen because of pain in the lower portion of the thigh of six months' duration. Physical examination revealed a palpable enlargement of the lower end of the right femur of the consistency of bone. Roentgenographic examination disclosed an area of destruction of the cortex about three centimeters in length on the medial aspect of the distal portion of the femur, about two centimeters proximal to the epiphyseal line. The shaft of the femur was thickened and in the lower one-third there were irregular, ill defined lytic areas. There was a minimal degree of periosteal reaction adjacent to the area of cortical destruction. A biopsy was performed but because of a severe respiratory infection in the patient, a hip disarticulation was delayed for three months. Gross examination of the amputated specimen

revealed an irregular, destructive lesion involving the medial two-thirds to three-fourths of the lower portion of the femur beginning three centimeters proximal to the ephiphyseal plate and extending for ten centimeters up the shaft of the femur, beyond which a few isolated tumor nodules were located. In the area of cortical destruction, which was located over the most distal portion of the tumor, a small amount of tumor tissue protruded into the adjacent connective tissue. There was some sclerosis of the bone adjacent to the tumor. The tumor itself was firm, gray-white, rubbery, with yellow areas of necrosis in its central portion. Microscopically, this tumor was mostly cellular, made up of fusiform cells with large vesicular nuclei, was moderately pleomorphic in some areas with a great deal of loss of polarity of the cells. However, in other areas there was fairly well defined polarity, though little fascicular arrangement. Mitotic figures were fairly frequent and there was considerable necrosis throughout the tumor.

Case 7. J.R.B., a twelve-year-old white boy, was seen because of pain in the lower portion of the right thigh of five months' duration, followed by swelling. Physical examination revealed a firm tumor over the lateral aspect of the right thigh just above the knee. Roentgenographic examination disclosed an irregular, lytic, somewhat trabeculated destructive lesion in the medial portion of the distal femoral metaphysis extending to within one centimeter of the epiphyseal line. There was little sclerosis adjacent to the tumor but considerable periosteal reaction. The cortex was destroyed on the medial aspect. A biopsy was done followed by amputation. Gross examination of the specimen revealed a tumor which was somewhat cystic and hemorrhagic in the central portion. Beginning at the lateral part of the metaphysis of the lower portion of the femur, within one centimeter of the epiphyseal plate, it extended medially to involve the entire shaft of the femur and extended up the shaft of the femur for nine centimeters. The cortex was destroyed in the metaphyseal region over an area about three centimeters in length, adjacent to which there was considerable periosteal reaction. Microscopic examination disclosed a highly cellular tumor of oval and fusiform cells with large hyperchromatic nuclei. There was marked pleomorphism, no organoid arrangement of cells, many mitotic figures, and almost no collagen formation.

Case 8. J.C.T. was a white man, thirty-seven years old, seen because of pain in the region of the left knee for two years and swelling just above the knee for nine months. He had had a fracture at about the junction of the middle and lower thirds of the femur approximately three years before. Physical examination revealed a mass over the medial and posterior aspects of the lower portion of the left femur. It was firm and there was a palpable bony thickening above the enlargement. Roentgenographic examination disclosed an irregular sclerosis and broadening of the shaft of the femur at the junction of the middle and lower thirds. Distal to this there was a slightly expansile lytic lesion extending to the articular cortex and destroying the cortex posteriorly. A high-thigh amputation was done. Examination of the gross specimen disclosed a gray-white, rubbery to hemorrhagic and partially necrotic tumor, extending to the femoral condyles posteriorly and directly across them, anteriorly to the cortex and then up the shaft of the femur for twelve centimeters. Posteriorly, the cortex was eroded and tumor extended for about four centimeters into the soft tissue. There was considerable sclerosis of the cortex anteriorly and the tumor extended up the shaft to the site of the old fracture where a diagonal bar of bone apparently blocked its progress. Microscopically, the tumor was composed of uniform, fusiform cells with scant cytoplasm and very rare mitotic figures. These cells were arranged in well defined fasciculi with a distinct whorled pattern and well defined palisading in some areas. Intervening between these were large areas of hyalinization with calcification.

Case 9. N.R., a white woman twenty-four years old, was seen because of pain in the lower third of the right thigh for one year, followed by swelling. There had been two episodes of rather severe trauma to this area, in the year previous to the onset of these symptoms. Physical examination revealed a firm, fusiform mass in the lower third of the right thigh just above the femoral condyles. There was considerable crepitation and pain upon manipulation of the area. Roentgenographic examination revealed an irregular lytic lesion, beginning four centimeters above the intercondylar fossa of the right femur and extending for twelve centimeters up the shaft of the femur. There were two irregular areas of destruction in the shaft. There was a pathological fracture, apparently of considerable age, through the lower portion of this lytic area about which there was some callus formation. A biopsy was done, followed by hip disarticulation. Examination of the gross specimen revealed the shaft of the femur to be filled with a reddish-brown to gray and translucent tumor for thirteen centimeters extending from a point two and one-half centimeters above the intercondylar fossa. In the region of the pathological fracture seen on the roentgenogram, the tumor protruded through and destroyed the cortex over an area of about five centimeters, extending beyond the cortical confines for two and one-half centimeters. Fragments of cortex completely disassociated from the remainder of the cortex overlay the extra-osseous part of the tumor. More proximally, in the femur, six centimeters from the calcar femorale, another tumor deposit of similar character had almost completely eroded the cortex, leaving only a thin shell. This mass measured two centimeters in diameter. Microscopically, the tumor was highly cellular in some areas with considerable hyalinization in others. The cells were oval, fusiform, and spindle-shaped with fair fascicular arrangement in some areas, whereas in others the cells were almost completely dis-

organized. In some areas the tumor was fairly pleomorphic, in others quite uniform. Mitotic figures were present in moderate number and there were a great many large, multinucleated giant cells and some hemosiderin deposition.

CASE 10. R.C.D., a white man, sixty-seven years old, was admitted because of pain and swelling in the upper portion of the left arm of three months' duration. Physical examination revealed that the upper third of the left arm was twice as large as the opposite member and somewhat tender. There was a palpable bone mass intimately attached to or in continuity with the humerus. Roentgenographic examination revealed an expansile lytic lesion involving the upper one-third of the humerus, although it did not extend to the articular surface. The cortex was thinned with only a minimal degree of reaction. Medially, there was cortical destruction with extension of the tumor into the soft tissue. There were focal areas of calcification throughout the tumor. A biopsy was performed and the tissue removed was friable, grayish, hemorrhagic in areas, but uniformly soft. The incision was made not in the part of the tumor protruding medially, but the approach was posterolateral to the cortex of the humerus. The patient refused further therapy. Microscopic examination of the tissue revealed an extremely cellular pleomorphic tumor. The cells were large, oval or spindle-shaped with vesicular nuclei and a fairly abundant cytoplasm. There was little intercellular collagen formation and almost no fascicular arrangement of the tumor cells. There were many tumor giant cells and frequent mitotic figures, some of which were abnormal.

CASE 11. S.C. was an eighteen-year-old white girl who was seen because of pain in the right knee of eight months' duration, and swelling of three months' duration. Physical examination revealed a firm, fixed mass posteriorly and medially, just above the femoral condyles. Roentgenographic examination disclosed an irregular, mottled lytic lesion in the distal femoral metaphysis, occupying the medial one-half, and extending five centimeters proximal from the old epiphyseal line. Peripherally, there was a considerable degree of periosteal reaction and evidence of soft-tissue tumor. A biopsy and amputation were done. Gross examination of the specimen disclosed a firm, gray-brown tumor extending from within one centimeter of the articular cortex of the distal portion of the femur proximally a distance of eleven centimeters. The cortex was destroyed medially, just above the condyle, and the tumor extended into soft tissue. There was dense, reactive periosteal bone proximal to the extra-osseous extension. Microscopically, this was a highly cellular tumor, the characteristic cells of which were oval or fusiform. There was marked pleomorphism, many mitotic figures, and little intracellular substance.

CASE 12. R.B., a nineteen-year-old white girl, was seen because of pain in the left hip of five months' duration and because of non-union of a fracture of the femoral neck of some weeks' duration. Since the patient was in a body spica cast, physical examination of the area was not possible. Roentgenographic examination revealed an irregular lytic lesion of the femoral head, neck, and upper part of the shaft which had expanded the bone and greatly thinned the cortex, but produced minimal periosteal reaction. There was a pathological fracture through this area. A biopsy was done through a lateral incision and the tumor was found to be occupying the region of the greater trochanter and neck of the femur as well as the immediately superficial soft tissue. The tissue removed from the femoral neck and greater trochanter was soft, gray-white, without any resistance to cutting, and with no evidence of calcification or bone tissue. Microscopically the tumor was extremely cellular but not very pleomorphic. The cells were oval, or spindle-shaped, and closely packed with practically no intercellular collagen. There were many mitotic figures, some abnormal, a few focal areas of necrosis, and no evidence of bone formation. Subsequent autopsy disclosed a metastatic tumor of the same type in the lungs.

CASE 13. C.C., a white man, thirty-nine years old, had limitation of function and swelling of his right knee for fourteen years following an injury. For six months prior to examination, pain in the knee had become increasingly severe. Physical examination revealed the right knee moderately swollen. The swelling was firm and indurated over the anterior and lateral surfaces of the joint and there was marked limitation of motion. Roentgenographic examination revealed a marked expansion of the distal femoral epiphysis, metaphysis and diaphysis, due to an irregular, mottled lytic lesion occupying this area with the exception of a small portion of the medial epicondyle. The cortex was markedly thinned in this expanded area, and anteriorly, the cortex was destroyed over an area of about three centimeters in the mid-portion of the tumor. There was no periosteal reaction. A biopsy was done followed by a high-thigh amputation. Examination of the gross specimen revealed that the distal portion of the femur was markedly enlarged due to expansion of the cortex beginning one centimeter proximal to the intercondylar fossa. Just above the condyles this expansion attained a maximum extent of eight centimeters in the anteroposterior diameter and ten centimeters in the lateral. The cortex was markedly thinned except at the point where expansion began, where there was some sclerosis, especially posteriorly. This expanded area was occupied by a rubbery tumor, varying from gray-white to red and yellow with a small cavity in the central portion surrounded by yellowish necrotic material. The cortex was destroyed anteriorly and the tumor extended into the soft tissue for one

centimeter. Microscopic examination revealed a fairly cellular, moderately pleomorphic tumor which in most areas showed a fair degree of fascicular arrangement or whorling of bundles of tumor cells. In some areas there was a considerable amount of intercellular collagenic material, but in others it was sparse. Mitotic figures were present in moderate number. Lymphocytic infiltration was fairly prominent.

CASE 14. F.H. was a woman, seventy-three years old, who was seen four weeks after she had fallen from a chair onto the right hip. She had had pain in this hip for approximately one year prior to the fall. Physical examination revealed the right leg in abduction and external rotation with tenderness over the greater trochanter. Roentgenographic examination revealed an old fracture of the femoral neck with upward displacement of the neck and greater trochanter. The greater trochanter was somewhat expanded and there were irregular lytic areas in it extending down the shaft of the femur to about two centimeters below the calcar femorale. There was no periosteal reaction but the cortex appeared eroded in the mid-portion of the greater trochanter. A biopsy was performed through an incision over the subtrochanteric region and a gray-white, semitranslucent, gritty tumor tissue was removed. No further operative treatment was done. Microscopic study revealed an extremely cellular, highly pleomorphic tumor of closely packed, oval to spindle-shaped cells with many mitotic figures.

CASE 15. K.L. was a white man, fifty-eight years old, who was seen because of pain in the left hip for a period of six months. Physical examination revealed only slight limitation of function in the left hip. Roentgenographic examination revealed an irregular, mottled lytic lesion in the upper part of the shaft, greater trochanter, and neck of the left femur. There was no expansion of the bone; the cortex was intact. A biopsy was carried out through the cortex of the greater trochanter and there was encountered a large, cystic cavity containing blood-stained fluid with a thin fibrous-tissue lining. The tissue removed was blood-stained, reddish-brown and granular, containing spicules of bone. Microscopic examination of this tissue disclosed a moderately cellular tumor of spindle-shaped cells with vesicular nuclei. There was a generous admixture of multinucleated giant cells, and moderate production of collagen but no bone. Six months after the original biopsy the patient was seen, complaining of considerable pain in the knee. Roentgenographic examination at this time revealed destruction of the bone chips which had been inserted into the cavity, and recurrence of the lytic lesion in the greater trochanter and neck and upper shaft of the femur with more extension into the femoral head. There was no cortical reaction but there was some expansion of the cortex in the trochanteric region. Two months later, roentgenographic examination revealed rapid progression of the destructive lesion which then extended down into the shaft of the femur, expanded the cortex in the region of the neck and greater trochanter, and penetrated the cortex medially, both in the region of the calcar femorale and laterally over the greater trochanter. Hip disarticulation was done at another institution and no record of the gross examination could be obtained. Microscopic examination revealed a cellular, moderately pleomorphic tumor with oval to spindle-shaped cells with vesicular nuclei and scattered mitotic figures. At this time the tumor was similar in character to that seen originally, but the cellular changes made a diagnosis of fibrosarcoma inescapable. Ten months following the disarticulation, the patient was seen because of pain in the stump. Examination revealed a palpable mass in this region. An exploratory operation was carried out in the stump of the left thigh and a cystic mass containing brownish fluid surrounded by yellow-pink, friable tumor tissue was encountered. Microscopically, examination of this tissue disclosed a cellular, markedly pleomorphic tumor composed of large oval, polyhedral and spindle-shaped cells with frequent mitotic figures, no organoid arrangement, and almost no collagen production. There were areas of necrosis.

CASE 16. W.H. was a forty-two-year-old white woman who was seen because of pain in the left knee of eight months' duration. Physical examination revealed the knee to be swollen, painful, and red. Roentgenographic study disclosed an irregular destructive lesion involving the distal femoral epiphysis and metaphysis, and extending to the cortex which was somewhat thinned. There was a minimal degree of periosteal reaction. Lesions interpreted as metastases were demonstrated in the lungs at this time. A biopsy of the medullary tumor was carried out through the medial condyle of the left femur. A gray-white friable tumor was exposed which was not vascular and contained very little granular material, and was easily cut with a knife. Microscopic examination revealed a tumor composed of oval and spindle-shaped cells with a well defined fascicular pattern. There was a moderate degree of pleomorphism and in some areas, fairly abundant intercellular collagenic material. Mitotic figures were present in moderate number.

CASE 17. W.R.S., a white woman, sixty-one years old, was seen because of pain and swelling of the left knee of six months' duration. Physical examination revealed a diffuse swelling of the left knee with associated tenderness. Roentgenographic examination revealed an irregular, lytic lesion in the distal femoral metaphysis. Associated with this was a moderate degree of periosteal reaction and a small area of cortical destruction posteriorly, just above the medial condyle. The anteroposterior view showed some evidence that this lesion extended up the shaft for a considerable distance. A biopsy was carried out on the medial aspect

of the lower portion of the femur where some tumor was found outside the cortical bone. The central cavity was curetted in this area, and subsequently an amputation was performed. Examination of the gross specimen revealed a tumor involving both condyles within two and one-half centimeters of the intercondylar fossa and extending proximally for a distance of eleven centimeters. The cortex was not expanded and not eroded except in one small area posteriorly, where it was considerably thinned out. The tumor was gray-pink, rubbery, and semitranslucent in some areas. Microscopic examination revealed a moderately cellular tumor composed of spindle-shaped cells, most of which had rather small, hyperchromatic nuclei with only occasional large, oval, or plump nuclei. There was practically no pleomorphism, a fair fascicular arrangement of the cells, and a considerable amount of intercellular collagenic material with only occasional mitotic figures.

CASE 18. J.W., a Negro man, twenty-eight years old, was seen because of a spontaneous fracture associated with considerable pain in the upper portion of the tibia two days previously. Eleven years before he had received irradiation therapy to this area for a soft-tissue tumor, the nature of which was not known. Physical examination disclosed an angular deformity of the tibia with crepitation and considerable swelling and tenderness. Roentgenographic examination revealed an irregular, lytic lesion in the proximal diaphysis and metaphysis of the tibia, producing some expansion and thinning of the cortex without any significant adjacent sclerosis. The cortex of the tibia was eroded laterally. A biopsy was done followed by amputation. Examination of the gross specimen revealed a cortical defect in the medial, lateral, and posterior aspects of the tibia, approximately three centimeters in diameter. The proximal tibial diaphysis and a portion of the metaphysis were occupied by an irregular, mottled, gray-red and yellow, rubbery tumor which had within it small cystic areas. The cortex of the tibia was thinned and expanded, particularly on the lateral aspect. This lesion occupied approximately ten centimeters of the tibia, extending well down the shaft in one area, up to within one centimeter of the articular surface. Microscopic examination revealed a fairly cellular tumor composed of small, spindle-shaped cells with apparently abundant cytoplasm and distinct cytoplasmic processes in some areas. Pleomorphism was not marked but there were scattered atypical nuclei and occasional mitotic figures. The tumor had a good fascicular arrangement with large bundles of cells coursing in a prominent whorled pattern. The tumor had infiltrated between bone trabeculae, many of which were dead.

CASE 19. D.H. was a sixteen-year-old white boy who was seen because of a painful mass over the upper aspect of the right tibia of four months' duration. Physical examination revealed a firm, fixed mass over the anterior aspect of the upper portion of the right tibia, measuring about four by six centimeters. Roentgenographic examination disclosed an irregular, lytic lesion involving the upper one-third of the right tibia, extending to the epiphyseal line and involving the anterior half of the bone with adjacent sclerosis, posteriorly. There was a moderate degree of periosteal reaction and there was cortical destruction over an area of about two centimeters, extending downward from the epiphyseal line. A biopsy was done and the tumor was found confined within a considerably thickened periosteum. The tibial canal was entered through a defect produced by the tumor and the tumor tissue curetted from the medullary space. The tumor seemed to extend downward for a distance of about six centimeters from the point where the tibia was entered. The tissue removed was gray-white, rubbery, and homogenous. There was only a small amount of bone within the tumor tissue. Microscopic examination revealed a cellular, moderately pleomorphic tumor with rather well defined fascicles composed of bundles of tumor cells. The nuclei showed a considerable variation in size but were in general plump or spindle-shaped. There was a moderate number of mitotic figures and a considerable amount of intercellular collagenic material. Hip disarticulation was done elsewhere but the report of the examination of the gross specimen was not available. Subsequently, the patient underwent a pulmonary resection for a metastatic lesion.

CASE 20. M.M.B., a white man seventy-two years old, was seen because of a fracture of the lower portion of the left femur resulting from a fall. Physical examination revealed shortening of the left thigh with angulation. Crepitation was elicited at the junction of the middle and distal thirds of the left femur. Roentgenographic examination disclosed a fracture at the junction of the middle and distal thirds of the left femur with little displacement. Proximal to the fracture site there was a vaguely outlined area of decreased density. An operation was performed and fixation of the fracture was maintained by an onlay bone graft. At this time a small cyst, two by three centimeters in diameter was discovered proximal to the fracture site. This was curetted and a small amount of soft, somewhat hemorrhagic fibrous tissue with grayish, shiny areas was removed. Microscopic examination of the tissue removed revealed a lesion, in some areas composed largely of hyalinized collagenic tissue but with small, fairly cellular areas of spindle-shaped cells, generally with large nuclei and considerable aberration in nuclear size and staining. In some areas there was a fairly marked giant-cell reaction. Mitotic figures were rare but the atypical changes in the fibroblastic cells were prominent. Five months after the operation it was apparent that there was recurrence of the cystic lesion in the shaft of the femur, which was found on serial studies to progress rapidly with gradual thinning and destruction of the cortex over the medial aspect of the femur. One year later it was apparent that the lesion had extended up the shaft of the femur, that the cortex was largely destroyed, and that the graft was being involved. An

amputation was performed. Examination of the gross specimen revealed a firm, white, rubbery tumor with focal areas of hemorrhage filling the medullary canal of the femur in the region of the old fracture for approximately eight centimeters. The cortex was destroyed anteriorly and medially but little tumor tissue extended into the adjacent soft tissue. Microscopic examination revealed a tumor similar to that seen originally, with large areas of relatively acellular hyalinized connective tissue, but with a number of focal areas of rather marked cellularity, made up of large spindle-shaped cells with bizarre nuclei and some tumor giant cells. Mitotic figures were infrequent but the tumor cells were manifestly atypical.

CASE 21. E.T.S., a white man, forty-seven years old, was seen because of pain in the upper portion of the right tibia for five months. Physical examination revealed a small, firm, fixed mass on the medial aspect of the upper portion of the tibia just below the joint space. Roentgenographic examination disclosed an irregular, lytic lesion on the medial aspect of the tibia just below the articular cartilage. The lesion was small and adjacent to it there was considerable increase in the density of the epiphysis and metaphysis. There was no periosteal reaction. Biopsy was carried out over this area and a small defect in the medial aspect of the tibia was discovered, through which a white rubbery tissue was protruding. An amputation was done. Examination of the gross specimen revealed a firm, gray-white tumor filling the proximal tibial diaphysis, metaphysis, and epiphysis, extending to the articular cartilage, and occupying a segment of the tibia nine centimeters in length. There was a small defect in the cortex just beneath the articular cartilage, medially, at the site of the biopsy. Microscopically, the tumor was only moderately cellular, composed of rather large spindle-shaped cells exhibiting considerable pleomorphism with many large, bizarre forms, and a moderate number of mitotic figures. Fascicular arrangement was not good although there was a considerable deposition of intercellular collagenic material. The tumor infiltrated diffusely through the medullary canal where most of the bone trabeculae were viable.

CASE 22. G.M., a white man fifty years old, was seen because of pain followed by swelling in the left knee for a period of six months. Physical examination revealed a firm, rubbery swelling of the upper medial, dorsal aspect of the left knee. Roentgenographic examination disclosed a lytic area in the distal femoral metaphysis about three centimeters in diameter. About this was a moderate degree of sclerosis and some periosteal new-bone formation. A biopsy was performed and tumor tissue was encountered outside of the cortex, but a window was made and the area of involvement within the medullary canal was curetted. An amputation was done. Examination of the gross specimen revealed a tumor filling the medullary canal in the distal diaphysis and metaphysis of the femur, extending into the diaphysis in an irregular fashion. The total area occupied was about six centimeters in length. The tumor eroded the cortex and extended through it anterolaterally into the region of the attachment of the joint capsule. The tumor was firm, gray-white, and rubbery. Microscopic examination revealed a cellular tumor composed of rather large, fusiform cells with large vesicular nuclei. These had a well defined pattern, often repeated throughout the tumor, of small whorled masses, giving the tumor, under low power, a picture of multiple galaxies of tumor cells. There was a moderate amount of intracellular collagen formation, little pleomorphism of tumor cells and a moderate number of mitotic figures.

RESULTS

Of the twenty-two patients, there was one immediate postoperative death (Case 20), one was too recent to include (Case 22), and one was without adequate follow-up (Case 14). Thus nineteen cases are available for final analysis.

The over-all cure rate was 26.3 per cent, five patients being alive and well for from fifteen to twenty-five years after operation. If, however, the two remaining Grade I tumors are not considered, the cure rate drops to 17.6 per cent.

Of those who died, the average survival time varied from three to sixty-one months, with an average of 14.5 months. In this group only one patient lived more than two years without evidence of metastases. Thus it seems that a patient surviving for two years has an excellent chance of being cured.

No patient with a Grade III tumor survived, while two with Grade I tumors survived. (The patient in Case 20 died four days postoperatively of pulmonary embolism.)

Of some interest is the fact that of the three patients who received Coley's toxin, one lived sixty-one months, and the other two are living and well at the time of writing.

DISCUSSION

Originally our attention was drawn to this group of lesions because we could not gain

any definite idea as to prognosis from a review of the literature, since there was an indiscriminate grouping of all fibrosarcomata involving bone. Strangely enough, certain writers, notably Stout, and Geschickter and Copeland, denied the existence of such a tumor, feeling that the tumors were of parosteal origin and that the involvement of bone was secondary in all cases.

We were convinced, however, both by observation and by reasoning, that central or medullary fibrosarcoma represented a separate entity, and found support in the studies of Phemister, Jaffe, and Lichtenstein.

Observation supports our contention in several ways. First, the statement of surgeons that the cortex overlying a tumor was intact and that windowing was necessary to reach the tumor, while not conclusive, certainly was suggestive. Second, roentgenographic studies made from various angles frequently revealed an intact cortex. Third, careful study of specimens following amputation revealed the tumor confined within the cortex, with no evidence at any point of extracortical extension.

In a logical consideration of the problem, certain conclusions are inescapable. First, we know from histological and tissue-culture studies that fibroblasts are present in the medullary connective tissue. It is axiomatic that where fibroblasts are present in the body, malignant transformation is possible. Second, the existence of benign central fibrous-tissue lesions, notably fibromata and fibrous dysplasia, is an undisputed fact. Thus malignant fibroblastic tumors in the same location are to be expected.

In general, the impression gained from the literature is that a diagnosis of fibrosarcoma automatically implies a good prognosis. Batts reported a 40 per cent five-year survival rate in twenty-five cases of periosteal fibrosarcoma. Pack and Ariel reported an astonishing 81.3 per cent five-year survival rate. In the seventy-eight cases reported by Ivins, Dockerty, and Ghormley, there is a 38 per cent five-year survival rate. Recently, Brindley, Phillips, and Fernandez found a 63 per cent five-year survival rate in thirty-five patients.

Admittedly, these reports refer to soft-tissue fibrosarcomata, and the great variation in cure rate in different series probably reflects the therapy employed. However, in the absence of reports specifically treating fibrosarcoma of bone there is a temptation to apply the statistics of soft-tissue tumors to primary bone lesions. Coley, for example, wrote that medullary fibrosarcomata are of low-grade malignancy and that radical surgery offers an excellent chance of cure.

Our study indicates that this is not true. The over-all cure rate in our series was 26.3 per cent, and if Grade I tumors, that is, the indolent, slow-growing lesions, are excluded, the cure rate drops to 17.6 per cent. Thus the prognosis in fibrosarcoma of the bone is far more grave than in the soft-tissue tumors.

Objections may be raised that our cases actually are of osteogenic sarcomata, and according to the classification of MacDonald and Budd, they are. However, in this classification the term *osteogenic sarcoma* simply indicates that the tumor arose in or from bone—no new idea, since Ewing's classification was modeled on this concept.

Currently, the consensus is that the term *osteogenic sarcoma* should be applied only to those highly anaplastic sarcomata usually occurring before the age of twenty and with about a 10 per cent survival rate. A diagnostic feature in these is the microscopic demonstration of the production of tumor bone and osteoid formation by the malignant cells.

In none of our cases of fibrosarcoma was this demonstrated, and clearly both the age distribution and prognosis in our cases differed considerably from those cases we designate as true osteogenic (bone-forming) sarcomata. For example, in an analysis, at this time incomplete, of the latter type of tumor in our Clinic, the median age is eighteen years with only three cases over the age of twenty. The average survival time is fourteen months and the cure rate 11 per cent. In all respects these statistics differ significantly from those reported in the current group of cases.

CONCLUSIONS

1. Central or medullary fibrosarcoma is an entity and must be considered separately from similar tumors arising in the periosteum or parosteally as well as from true osteogenic (bone-forming) sarcomata.

2. The five-year survival rate in these tumor cases is much worse than in those of soft-tissue sarcomata of similar nature, but appreciably better than in those of true osteogenic sarcoma.

3. From our series it would seem that once a patient has survived for two years, the chance of a permanent cure is good.

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Biochemical Studies of Articular Cartilage

I. Normal Values *

BY LILLIAN EICHELBERGER, PH.D., WAYNE H. AKESON, M.D., AND MICHAEL ROMA, CHICAGO, ILLINOIS

From the Division of Orthopaedic Surgery and the Department of Biochemistry, the University of Chicago, Chicago

The material to be presented in this paper is a continuation of a study on the tissue cartilage that was begun in 1950. The data on articular cartilage that we have obtained will establish more fully the normal values for hyaline cartilage, the normal mean values for costal cartilage having been given in 1954[5]. These normal values for articular cartilage taken from the joint surfaces of puppies will provide a base line for the normal mean values for future investigative studies of both normal and pathological cartilage in the biochemical, histological, and electron microscopical fields.

Few histochemical studies have been made on articular cartilage tissues from puppies of known ages. A complete review of all previous work on cartilage was summarized by Manery[10] in 1954.

The present study includes analytical data from thirty-one normal puppies apportioned as follows: Group I, six to twelve weeks of age; Group II, thirteen to fourteen weeks of age; Group III, fifteen to sixteen weeks of age; Group IV, seventeen to twenty weeks of age; and Group V, twenty-one to twenty-five weeks. Serum and cartilage from front and hind joints were analyzed separately in all groups except in Group V in which the front and hind limb specimens had to be combined for analyses because of the small amount of cartilage tissue obtainable at this age.

PROCEDURES AND METHODS

The puppies from which the cartilage specimens were obtained were bred by us in special metabolism cages in an isolated puppy room. The puppies were weaned at eight weeks of age and were then fed four times a day with standard commercial dog food supplemented with milk. At a specified age, the puppies were killed to obtain the cartilage from the joints of the front limbs and from the hind limbs. The puppies ranged in ages from six weeks to twenty-five weeks.

The tissues were taken from all puppies under nembutal anaesthesia. Before the removal of the limbs, fifty milliliters of blood were taken from the femoral artery for serum analyses. The limbs were then removed and each limb was wrapped in heavy aluminum foil to prevent water loss. The skeletal muscle was first removed from the extremity after which the joints were exposed. The cartilage was removed as follows: A small, weighed weighing bottle with a ground-glass stopper was used to collect all cartilage samples. At the instant that the joint was opened, the cartilage tissue was shaved from the articular surface and dropped into the weighing bottle, the bottle being kept closed except at the moment of dropping in the shaved pieces of cartilage tissue. The first sample or aliquot taken was weighed immediately for the water content of the tissue. A second weighed weighing bottle was used to collect the remainder of the cartilage shavings. Care was taken at all times that the scalpel did not penetrate the zone of calcification or the subadjacent articular cortex of bone. This procedure was never accomplished perfectly. The

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weighed tissue samples were next placed in an oven at 100 degrees centigrade for forty-eight hours or until constant weight was reached. The weighing bottles were then removed from the oven, closed with their respective ground glass stoppers, and placed in a desiccator over activated alumina for cooling and reweighing. The difference between this dry weight of the tissue and the original weight was the weight of the water in the sample.

All of the dry samples of any one specimen of cartilage were transferred to a Zassenhaus spice mill and were ground to a fine powder[7]. The finely ground powder was then transferred back to a small screw-top vial and was again dried in an oven at 100 degrees centigrade for approximately three hours, after which the cover was replaced and the specimen cooled in a desiccator over activated alumina. Aliquot samples from the ground tissue were weighed for all analyses.

Chemical Methods

In the analysis of the serum, the amounts of water, chloride, sodium, potassium, calcium, magnesium, and total nitrogen were determined; in the analysis of the cartilage, the amounts of water, chloride, sodium, potassium, calcium, magnesium, total nitrogen, collagen nitrogen, and sulphate were determined. Insufficient amounts of cartilage in some specimens limited the number of determinations that could be carried out. The chemical methods were approximately the same as described in previous papers[4, 6]. Some changes have been incorporated and these details will be listed.

In the analyses for chloride, approximately fifty milligrams of dry cartilage powder were weighed on a strip of aluminum foil 2.5 by 15.3 centimeters bent slightly to make a trough. The foil containing the weighed sample was held parallel with and inside a heavy walled tube 200 by thirty millimeters. On erection of the tube and foil, the sample fell into the bottom part of the tube. To obtain the exact weight of the sample, the foil containing the trace of the powdered sample remaining was reweighed, the difference being the weight of the sample placed in the tube. One milliliter of fifty millimol solution of silver nitrate and two milliliters of water were added to the tube which was allowed to stand overnight while covered with a small beaker. This standing of the dry sample with water is imperative. Two milliliters of concentrated nitric acid were then added to the tube followed by a small Cargille boiling stone and the mixture digested over a small flame for one hour while the tube remained covered with the small beaker. It was important that the mixture be kept at the boiling point and that a total volume of approximately three milliliters be maintained throughout the digestion period. After cooling the tubes in a refrigerator, the excess silver nitrate was titrated with 0.02 N ammonium thiocyanate by the Van Slyke method.

In the analyses of sodium and potassium on the Perkin-Elmer flame photometer, samples of fifty to 100 milligrams of the dry powder of the cartilage were weighed into fifteen-milliliter silica crucibles. After addition of one milliliter of 4 N sulphuric acid and drying in an oven at 110 degrees centigrade the tarry mass was placed in a muffle furnace and ashed at 525 to 550 degrees centigrade overnight. When cool, three drops of concentrated hydrochloric acid were added to each crucible and the contents were transferred to a twenty-five milliliter volumetric flask containing 2.5 milliliters of the stock lithium nitrate solution used for background in the flame. From this original twenty-five milliliter solution all aliquots for sodium and potassium determinations were taken for dilution for the flame photometric work. Since the original twenty-five milliliter solution had a one to ten dilution of the stock lithium nitrate, it was necessary to make all the dilutions for the sodium and potassium with a one to ten lithium nitrate solution.

RESULTS AND DISCUSSION

A summary of the original data for all analyses for all groups is given in Table I. The means for serum and cartilage from the front limb and cartilage from the hind limb

TABLE I*†

MEAN VALUES FOR ARTICULAR CARTILAGE FROM PUPPIES
ORIGINAL DATA

	H_2O (gm.)	Cl (meq.)	Na (meq.)	K (meq.)	Ca (meq.)	Mg (meq.)	Total N (gm.)	Collagen N (gm.)	CSA (gm.)
Group I: 6–12 weeks of age (5)									
Tissue									
serum	951.1	115.9	145.3	4.64	6.20	2.32	7.86		
Standard deviation	0.3	1.0	1.7	0.20	0.09	0.04	0.13		
Cartilage									
Front	801.4	32.19	102.3	11.70	14.09	6.23	12.60	8.28	18.5
Standard deviation	13.0	3.38	11.0	1.19	1.72	1.47	0.79	0.43	1.7
Hind	799.7	32.34	108.5	11.71	13.22	5.90	12.60	8.17	19.8
Standard deviation	12.0	3.47	8.4	0.90	1.63	0.65	0.49	0.53	2.0
Group II: 13–14 weeks of age (6)									
Tissue									
serum	935.8	111.6	146.0	4.74	5.63	2.22	7.74		
Standard deviation	1.3	2.6	2.7	0.32	0.43	0.24	0.14		
Cartilage									
Front	779.4	29.46	96.1	10.66	19.63	6.18	13.31	9.11	16.1
Standard deviation	4.3	2.0	5.1	1.61	7.9	1.76	0.19	0.34	1.2
Hind	782.7	30.73	102.4	10.45	16.72	5.67	13.40	8.90	16.4
Standard deviation	6.2	0.74	7.6	1.61	3.97	0.77	0.37	0.25	1.3
Group III: 15–16 weeks of age (6)									
Tissue									
serum	928.1	111.1	145.7	5.01	5.80	2.08	8.92		
Standard deviation	7.6	2.9	3.9	0.38	0.38	0.13	0.92		
Cartilage									
Front	772.8	30.13	86.76	9.28	14.41	5.22	13.87	9.16	15.7
Standard deviation	5.2	1.63	4.70	0.61	3.63	0.95	0.53	0.35	3.1
Hind	774.5	30.80	90.63	9.05	13.70	4.70	13.64	9.27	15.3
Standard deviation	8.2	2.80	9.4	0.72	2.05	0.54	0.34	0.46	0.9
Group IV: 17–20 weeks of age (8)									
Tissue									
serum	930.1	110.1	146.9	5.06	5.68	1.91	8.48		
Standard deviation	2.6	1.7	1.2	0.25	0.33	0.24	0.41		
Cartilage									
Front	753.7	27.16	78.32	8.55	20.15	3.91	13.66	9.18	12.3
Standard deviation	9.1	1.11	7.8	0.50	2.71	0.63	0.72	0.77	1.5
Hind	766.3	30.74	79.34	9.09	23.18	4.60	13.50	8.89	11.7
Standard deviation	13.6	1.74	10.00	0.53	1.42	0.14	0.70	0.70	1.7
Group V: 21–25 weeks of age (6)									
Tissue									
serum	927.0	109.7	142.5	4.87	5.60	2.39	8.54		
Standard deviation	2.6	1.4	3.2	0.17	0.11	0.33	0.38		
Combined cartilage	747.7	27.53	76.74	8.37	34.95		13.47	9.59	9.1
Standard deviation	13.8	1.65	10.30	1.18	17.5		0.41	0.81	1.7

* Serum values are given in units per kilogram of serum.

† Cartilage values are given in units per 100 grams of cartilage solids except water values which are given in grams per kilogram of fresh cartilage.

for each group are given with standard deviations, the figures in parentheses being the number of puppies contributing to these means. These original data provide a basis for a number of deductions, some by direct observation and others by calculation.

Values for Cartilage from Front Limb and Hind Limb

No significant differences are noted in the mean values for the articular cartilage from front and hind limbs in the first three groups of puppies which comprise the first sixteen weeks of life. In Group IV, seventeen to twenty weeks of age, although eight

TABLE II *

HISTOCHEMICAL DATA FOR ARTICULAR CARTILAGE SOLIDS

Estimated Weight of Extracellular $(E)_s$ and Intracellular $(C)_s$ Solids in 100 grams of Cartilage Solids

Group	Age (*Weeks*)	$(E)_s$ (*gm.*)	$(C)_s$ (*gm.*)	$(F)_s$ (*gm.*)	CSA_s (*gm.*)	Wt. Δ Na_s (*gm.*)
I.	6–12					
Cartilage						
Front		73	27	52	19	2.1
Hind		74	26	52	20	2.5
II.	13–14					
Cartilage						
Front		76	24	58	16	1.9
Hind		74	26	56	16	2.1
III.	15–16					
Cartilage						
Front		76	24	58	16	1.7
Hind		76	24	59	15	1.8
IV.	17–20					
Cartilage						
Front		71	29	58	12	1.5
Hind		69	31	56	12	1.6
V.	21–25					
Combined cartilage		71	29	61	9	1.5

* Subscript small s refers to 100 grams cartilage solids.

$(F)_s$ = grams connective tissue solids in 100 grams cartilage solids = $100 \times (\text{collagen N})_s/15.8$

CSA_s = weight of chondroitin sulphate in 100 grams cartilage solids (calculated from Levene's molecular weight $\Leftrightarrow$ 2 moles of SO_4) [8]

Δ = total cartilage amount − amount associated with connective-tissue solids $(F)_s$

Δ Na = sodium not associated with connective-tissue = total sodium − amount of sodium associated with $(F)_s$

Milliequivalents Na associated with $(F)_s = 20.2 \times (F)_s/100$

$(E)_s$ = grams of extracellular solids in 100 grams cartilage solids = $(F)_s + CSA_s + \Delta Na_s$

$(C)_s$ = grams of intracellular solids in 100 grams cartilage solids = $100 - (E)_s$

puppies are included, the values for the front limb and hind limb are not quite so consistent as in the younger groups. The data for all groups indicate that the articular cartilage from the joints of the front limb and the hind limb are alike in water, nitrogen, electrolyte, and chondroitin sulphate distribution. Therefore, up to the age of seventeen weeks, it is not necessary to separate the limbs for chemical analysis. The slight difference found in Group IV may be the result of defective removal of the cartilage from the subadjacent zone of calcification or the beginning of some deposition of calcium salts along the fibers adjoining the subadjacent bone layer beneath the cartilage.

It will be noted that the water content decreases in amount as the puppies age. In the puppies six to twelve weeks old, the water content was 80 per cent; in the puppies thirteen to fourteen weeks old, the water content was 78 per cent; in puppies fifteen to sixteen weeks old, 77 per cent; in puppies seventeen to twenty weeks old, 76 per cent; and

in puppies twenty-one to twenty-five weeks old, the water content dropped to an average of 75 per cent. Along with this decrease in water content is a decrease in the total chloride content. A definite decrease was found in the weight of the chondroitin sulphate per 100 grams of cartilage solids as the puppies increase in age, while there was a simultaneous decrease in the total sodium content. In calcifying costal cartilage the reverse was found[5].

Histologically, cartilage is known to be composed of chondrocytes surrounded by extracellular fluid, connective-tissue fibers, and chondroitin sulphate complex. That having been shown, we have considered that the extracellular compartment of cartilage consists of: (a) a fluid phase, and (b) a solid phase of connective tissue and chondroitin

TABLE III *†

PHASE MASS DATA FOR ONE KILOGRAM OF ARTICULAR CARTILAGE
DERIVED SOLIDS

Group	Age (*Weeks*)	Total Water (*gm.*)	Total Solids (*gm.*)	$(F)_S$ (*gm.*)	CSA_S (*gm.*)	Wgt. Δ Na_S (*gm.*)	$(E)_S$ (*gm.*)	$(C)_S$ (*gm.*)
I.	6–12							
Cartilage								
Front		801	199	104	38	4	146	53
Hind		800	200	104	40	5	149	51
II.	13–14							
Cartilage								
Front		779	221	128	35	4	167	54
Hind		783	217	122	35	5	162	55
III.	15–16							
Cartilage								
Front		773	227	132	36	4	172	55
Hind		774	226	133	34	4	171	55
IV.	17–20							
Cartilage								
Front		754	246	143	29	4	176	71
Hind		766	234	131	28	4	163	71
V.	21–25							
Combined cartilage		748	252	154	23	4	181	71

* Units are expressed per kilogram of fresh cartilage.
† Subscript capital S refers to one kilogram of fresh cartilage.
All estimated values for $(F)_S$; CSA_S; Wgt. Δ Na_S; $(E)_S$; and $(C)_S$ are obtained from the weights in 100 grams of cartilage solids in Table II and the determined total solids.
$(F)_S$ = grams connective tissue solids per kilogram fresh cartilage = $(F)_s \times$ total solids/100
CSA_S = grams chondroitin sulphate per kilogram fresh cartilage = $CSA_s \times$ total solids/100
Wgt. Δ Na_S = Wgt. Δ $Na_s \times$ total solids/100
$(E)_S$ = extracellular solids per kilogram fresh cartilage = $(F)_S + CSA_S +$ Wgt. Δ Na_S
$(C)_S$ = intracellular solids per kilogram fresh cartilage = total determined solids $- (E)_S$

sulphate complex, and that there is an intracellular compartment consisting of water and protein solids.

The major consideration for any organized tissue such as cartilage is the assignment of the chemical constituents to the separate compartments. Up to the present time, we have not been able to separate the cells of tissues from the extracellular fluid and the solid structures in the extracellular compartment. For analyses therefore only a sample of the whole tissue, including all of its components, has to be analyzed. From these determined values, calculations have to be made for the estimation of the masses of the extra and intracellular compartments and for the concentration of constituents inside and outside the chondrocytes by employing the best information available at this time.

We conform to the accepted view that chondrocytes of cartilage are free of chloride[2] and that all of the chloride is confined to the extracellular water compartment. If the

concentration of chloride of the extracellular fluid is known $(Cl)_U$, then the volume of the extracellular water in the cartilage tissue can be calculated (Table IV). $(H_2O)_E = (Cl)_S/(Cl)_U \times 1000$. If this extracellular amount of water is subtracted from the total amount found by analyses in a sample of whole tissue, the remaining water represents the amount existing in the chondrocytes (intracellular water).

There is no direct method now of partitioning solids as found by the analyses of the whole tissue between the extracellular and intracellular compartments. We have used therefore the concentration of tendon-like proteins to estimate the connective-tissue solids in the extracellular compartment of the cartilage and sulphate analyses to estimate the weight of the chondroitin sulphate. Manery and associates have established experimentally that the water and electrolyte patterns of all connective tissues resemble each other closely, and consequently we have assumed that the connective tissue of cartilage corresponds in water and electrolyte concentrations to all other connective tissues. Thus we have used the densest of the connective tissues, tendon, for our reference tissue.

TABLE IV *

PHASE MASS DATA FOR ONE KILOGRAM OF ARTICULAR CARTILAGE
DERIVED WATER

Group	Age (*Weeks*)	$(F)_S$ (*gm.*)	$(H_2O)_F$ (*gm.*)	$(Cl)_F$ (*meq.*)	$(Cl)_S$ (*meq.*)	ΔCl_S (*meq.*)	Cl_U (*meq.*)	$(H_2O)_U$ (*gm.*)	$(H_2O)_E$ (*gm.*)	$(E)_S$ (*gm.*)	$(H_2O)_C$ (*gm.*)	$(C)_S$ (*gm.*)	$\{H_2O\}_C$ (*gm.*)
I.	6–12												
Cartilage													
Front		104	163	21.5	63.9	42.4	127.0	334	497	146	304	53	852
Hind		104	163	21.5	64.7	43.2		340	503	149	297	51	854
II.	13–14												
Cartilage													
Front		128	201	26.4	65.0	38.6	123.0	314	515	167	264	54	834
Hind		122	192	25.2	66.7	41.5		337	529	162	254	55	822
III.	15–16												
Cartilage													
Front		132	207	27.3	68.5	41.2	124.8	330	537	172	236	55	812
Hind		133	209	27.5	69.7	42.2		339	548	171	226	55	805
IV.	17–20												
Cartilage													
Front		143	225	29.6	67.0	37.4	124.0	302	527	176	227	71	762
Hind		131	206	27.1	72.0	44.9		362	568	159	198	71	740
V.	21–25												
Combined cartilage		154	242	31.8	69.5	37.7	123.3	306	548	181	200	71	740

*$(F)_S$ = Table III.
$(H_2O)_F$ = grams water associated with $(F)_S = 157 \times (F)_S/100$
$(Cl)_F$ = milliequivalents chloride associated with $(F)_S = 20.65 \times (F)_S/100$
$(Cl)_S$ = milliequivalents chloride per kilogram fresh cartilage = $(Cl)_s \times$ total solids/100
$\Delta Cl_S = (Cl)_S - (Cl)_F$
Cl_U = milliequivalents chloride per kilogram serum water $\times$ 0.0099/0.0095
$(H_2O)_U$ = grams ultrafiltrate water = $\Delta Cl_S \times 1000/Cl_U$
$(H_2O)_E = (H_2O)_F + (H_2O)_U$
$(E)_S$ = see Table III = $(F)_S + CSA_S +$ Wgt. Δ Nas
$(H_2O)_C$ = total water $- (H_2O)_E$
$(C)_S$ = see Table III = total determined solids $- (E)_S$
$\{H_2O\}_C$ = grams of water per kilogram of chondrocytes = $(H_2O)_C \times 1000/(H_2O)_C + (C)_S$

The recent work of Mathews shows that sodium chondroitin sulphate is present in cartilage in the form of a non-collagenous protein complex. Therefore, it is necessary for the weight of the connective-tissue solids (collagenous) and the chondroitin sulphate solids (non-collagenous) to be expressed separately.

From our analytical data, therefore, the histochemical characterization of the

inorganic constituents, the connective tissue, and chondroitin sulphate of the extracellular and cellular compartments has been made for this tissue and is presented in Tables II, III, and IV. In Table II, the histochemical data were estimated for 100 grams of the articular cartilage solids. The extracellular mass, labeled $(E)_s$, in 100 grams of the total solids is considered to be the sum of the connective-tissue solids $(F)_s$, plus the weight of the chondroitin sulphate $(CSA)_s$, plus the weight of the ΔNa_s which is the sodium in excess of that identified with the connective-tissue solids. The total extracellular mass is

TABLE V-A *

DISTRIBUTION OF POTASSIUM BETWEEN SERUM AND CARTILAGE PHASES

Group	$[K]_F$ (meq.)	In Extracellular Phase				$\{K\}_C$ (meq.)	$[K]_C$ (meq.)
		$(K)_T$ (meq.)	In $(H_2O)_U$ (meq.)	+ Assoc. with $(F)_S$ (meq.)	In (C) (meq.)		
I.							
Serum	4.63						
Cartilage							
Front		23.65	1.54	4.34	18.4	51.0	59.8
Hind		23.42	1.57	3.50	18.3	52.6	61.8
II.							
Serum	4.81						
Cartilage							
Front		23.65	1.54	4.34	17.6	55.7	67.2
Hind		22.70	1.62	4.14	17.0	55.2	67.2
III.							
Serum	5.13						
Cartilage							
Front		21.05	1.69	4.48	14.9	51.1	63.1
Hind		20.50	1.74	4.51	14.3	50.8	63.3
IV.							
Serum	5.16						
Cartilage							
Front		21.05	1.67	4.86	14.5	48.8	64.0
Hind		21.30	1.94	4.46	14.9	55.4	75.2
V.							
Serum	4.99						
Combined cartilage		21.10	1.53	5.24	14.3	52.9	71.6

* $[K]_F$ = milliequivalents K per kilograms of extracellular fluid = milliequivalents K per kilogram of serum water × 0.95
$(K)_T$ = milliequivalents K per kilogram of fresh cartilage = milliequivalents $(K)_s$ × total solids/100
In $(H_2O)_U$ = milliequivalents K in ultrafiltrate = $[K]_F \times (H_2O)_U$ (Table IV)/1000
Associated with $(F)_S$ = milliequivalents K associated with $(F)_S = 3.4 \times (F)_S/100$
In (C) = milliequivalents K in chondrocytes = $(K)_T$ − (In $(H_2O)_U$ + assoc. with $(F)_S$)
$\{K\}_C$ = milliequivalents K per kilogram chondrocytes = $(K)_C \times 1000/(H_2O)_C + (C)_S$
$[K]_C$ = milliequivalents K per kilogram chondrocyte water = $(K)_C \times 1000/(H_2O)_C$

then subtracted from the 100 grams to obtain the mass of the cell or chondrocyte solids.

We assume that the connective tissue of cartilage corresponds to all other connective tissue and we have used the assembled data for tendon analyses to calculate the weight of the connective tissue in the total cartilage solids. From the weight of the connective-tissue solids we have estimated the amounts of chloride, sodium, and potassium identified with this calculated amount of connective-tissue solids. Our previous work on tendon[3] established that 100 grams of tendon solids are associated with 157 grams of water, 17.2 grams total nitrogen, 15.8 grams of collagen nitrogen, 20.65 milliequivalents of chloride, 20.2 milliequivalents of sodium, and 3.4 milliequivalents of potassium[9].

From the original data (Table I) and the description of the amounts of extracellular solids and the cellular solids in 100 grams of total cartilage solids (Table II), the mass of

the extra and intracellular compartments per kilogram of fresh cartilage can be estimated. The estimations are given in Tables III and IV with all of the equations given in detail for the calculations. From Table III, it will be observed that the connective-tissue solids $(F)_s$ increase from a value of 104 grams to 154 grams as the puppies increase in age. The chondroitin sulphate however decreases in weight from thirty-eight grams to twenty-three grams. Even though the chondroitin sulphate decreased in weight, the connective-tissue mass increases enough to bring up the total extracellular solids from a value of 146 grams

TABLE V-B *

DISTRIBUTION OF MAGNESIUM BETWEEN SERUM AND CARTILAGE PHASES

Group	$[Mg]_F$ (*meq.*)	$(Mg)_T$ (*meq.*)	In $(H_2O)_E$ (*meq.*)	In (C) (*meq.*)	$\{Mg\}_C$ (*meq.*)	$[Mg]_C$ (*meq.*)
I.						
Serum	1.82					
Cartilage						
Front		12.4	0.90	11.5	32.2	37.8
Hind		11.8	0.91	10.9	31.3	36.7
II.						
Serum	1.66					
Cartilage						
Front		13.6	0.86	12.8	40.2	48.5
Hind		12.3	0.88	11.5	37.1	45.1
III.						
Serum	1.69					
Cartilage						
Front		11.8	0.91	10.9	37.5	46.2
Hind		10.6	0.93	9.7	34.5	43.0
IV.						
Serum	1.55					
Cartilage						
Front		9.62	0.85	8.8	30.4	38.6
Hind		10.8	0.90	9.7	35.9	48.8

*$[Mg]_F$ = milliequivalents Mg per kilogram extracellular fluid = $\sqrt{[Mg]_F}/\sqrt{Mg/kg}$ serum water = 0.837
$(Mg)_T$ = milliequivalents Mg per kilogram fresh cartilage = meq $(Mg)_s \times$ total solids/100
In $(H_2O)_E$ = milliequivalents Mg in $(H_2O)_C + (H_2O)_F = [Mg]_F \times (H_2O)_E/1000$
In (C) = milliequivalents Mg in chondrocytes = $(Mg)_T$ − In $(H_2O)_E$
$\{Mg\}_C$ = milliequivalents Mg per kilogram chondrocytes = $(Mg)_C \times 1000/(H_2O)_C + (C)_S$
$[Mg]_C$ = milliequivalents Mg per kilogram chondrocyte water = $(Mg)_C \times 1000/(H_2O)_C$

to 181 grams as the puppies increase in age. Simultaneously, the cell solids increase from a solid mass of forty-three grams to a value of seventy-one grams. This result corresponds to the findings in soft tissues in which the cell mass increases as an animal increases in age[1,10].

Table IV gives the assembled data for the derived extracellular water $[(H_2O)_F$ and $(H_2O)_U]$ and the derived intracellular water, $(H_2O)_C$. The derived compartments of the tissues appear in the last five columns of this table. For example, reading from the table, for one kilogram of front-limb cartilage of Group I, the extracellular phase mass is 643 grams of which 146 grams are the solids of this phase and 497 grams are the water, leaving a cell mass of 357 grams of which fifty-three grams are the cell solids and 304 grams, the cell water. Likewise, the patterns for all other cartilage in the groups can easily be read and plotted. It is interesting to note that the percentage of water of the chondrocytes $\{H_2O\}_C$ is quite constant through the sixteen-week age groups, an average of 83 per cent. In the older groups an average of 75 per cent was found. Also if all of the animals of the first three groups are considered for average mass values for the tissue compartments the findings are very consistent and are as follows: for the extracellular compartment the

extracellular water $(H_2O)_E$ = 522 grams and the extracellular solids $(E)_S$ = 161 grams, or a total of 683 grams, leaving 317 grams for the weight of the chondrocytes of which 263 grams are the chondrocyte water and 54 grams the chondrocyte solids. For the older puppies, seventeen to twenty-five weeks of age, the mass values are not as consistent. The average mass values are 548 grams of extracellular water + 172 grams of extracellular solids, making a total of 720 grams for the extracellular compartment. The remaining 280 grams are the weight of the chondrocytes, of which 209 grams are the chondrocyte water and 71 grams, the solids.

TABLE VI*

DISTRIBUTION OF SODIUM BETWEEN SERUM AND ARTICULAR CARTILAGE

Group	$[Na]_F$ (meq.)	$(Na)_T$ (meq.)	Extracellular Phase: In $(H_2O)_U$ + Assoc. with $(F)_S$ (meq.)		Δ Na (meq.)	CSA_S (mM)
I.						
Serum	144.5					
Cartilage						
Front		204.8	48.3	21.0	135.5	78.6
Hind		217.0	49.1	21.0	146.9	79.0
II.						
Serum	148.2					
Cartilage						
Front		212.4	46.5	25.8	140.1	75.9
Hind		222.2	49.9	24.6	147.7	76.0
III.						
Serum	149.1					
Cartilage						
Front		196.9	49.2	26.7	121.0	76.6
Hind		203.9	50.5	26.9	127.6	73.6
IV.						
Serum	150.0					
Cartilage						
Front		192.9	45.4	28.9	118.6	64.7
Hind		185.4	54.3	26.5	104.5	58.4
V.						
Serum	146.0					
Combined cartilage		193.4	44.7	31.1	117.6	48.9

* $[Na]_F$ = milliequivalents Na per kilogram extracellular fluid = milliequivalents Na per kilogram serum water × 0.95
$(Na)_T$ = milliequivalents Na per kilogram fresh cartilage = milliequivalents $(Na)_s$ × total solids/100
In $(H_2O)_U$ = milliequivalents Na in ultrafiltrate = $[Na]_F \times (H_2O)_U/1000$
Associated with $(F)_S$ = milliequivalents Na associated with $(F)_S = 20.2 \times (F)_S/100$
Δ Na = total determined sodium − Na in extracellular phase = $(Na)_T$ − [In $(H_2O)_U$ + Associated $(F)_S$]
CSA_S = mM chondroitin sulphate per kilogram of fresh cartilage

Using all of the histochemical patterns for one kilogram of cartilage from all of the age groups, we can show by histochemical means the distribution of potassium and magnesium in this tissue. Table V shows the estimated amounts in the extracellular compartment and in the cellular compartment (C) from which the concentrations were calculated for both a kilogram of chondrocytes and a kilogram of chondrocyte water. The potassium values are given first, followed by the magnesium values.

If the concentration of potassium is considered, that is the values expressed per kilogram of chondrocytes $\{K\}_C$ or per kilogram of chondrocyte water $[K]_C$, the concentrations are approximately the same for all age groups presented here, the average values being fifty-three milliequivalents of potassium per kilogram of chondrocytes and sixty-six milliequivalents per kilogram of chondrocyte water. If one considers content of potassium,

it was observed that in 100 grams of cartilage solids the potassium content decreased in amount, eleven milliequivalents to eight milliequivalents (Table I) as age increased; or expressed per kilogram of fresh cartilage the values likewise decreased from an average value of twenty-three milliequivalents to twenty-one milliequivalents.

The magnesium of cartilage is mostly intracellular. If the total magnesium content in a kilogram of fresh cartilage is corrected for the magnesium in the extracellular water $(H_2O)_E$, there remains an amount which is allocated to the chondrocytes (C). From these values the average magnesium per kilogram of chondrocytes amounted to thirty-five milliequivalents and that of the chondrocyte water averaged forty-three milliequivalents. Attention is drawn to the fact that the sum total of potassium and magnesium concentration amounted to eighty-eight milliequivalents per kilogram of chondrocytes, or 109 milliequivalents per kilogram of chondrocyte water. It is interesting that the concentration of magnesium in these cells is greater than that of the soft-tissue cells, while the concentration of potassium in the chondrocytes is less than half that of the soft-tissue cells[6,10]. It seems likely, therefore, that some other cation is present in the chondrocytes.

In spite of the uncertainties which make it impossible to interpret completely the quantitative distribution of sodium in the tissue compartments in the same manner as potassium and magnesium, it is possible to project some tentative conclusions in this direction. Table VI gives some of the distribution values. The determined sodium $(Na)_T$ was corrected for the sodium associated with the connective tissue and the sodium in the ultrafiltrate water $(H_2O)_U$, leaving an amount of sodium which we have designated as Δ Na. By speculation this is the amount of sodium that must be associated with the chondroitin sulphate. It is noted that when the chondroitin sulphate values are high, the Δ Na is high and conversely; for that reason the millimols of chondroitin sulphate were also included in this table for ready reference. We do not know at this time whether one or both of the hydrogen atoms of the chondroitin sulphuric acid are replaceable by sodium. Further investigative work therefore is needed for the placement of these Δ Na values.

SUMMARY

The histochemical characterization of articular cartilage from front and hind limbs of puppies up to twenty-five weeks of age has been presented. The average mass patterns for one kilogram of fresh cartilage were as follows: Through sixteen weeks of age, the extracellular compartment consisted of 522 grams of extracellular water $(H_2O)_E$ and 161 grams of extracellular solids $(E)_S$ or a total of 683 grams, leaving 317 grams for the weight of the chondrocytes (C), of which 263 grams are the chondrocyte water $(H_2O)_C$ and 54 grams, the chondrocyte solids $(C)_S$. For the older puppies, seventeen to twenty-five weeks of age, the extracellular-compartment mass was 720 grams of which 548 grams were $(H_2O)_E$ and 172 grams, $(E)_S$. The intracellular compartment or the weight of (C) was 280 grams of which 209 grams were $(H_2O)_C$ and 71 grams, $(C)_S$. Using these patterns for articular cartilage, the distribution and concentration of constituents in these tissues have been presented and discussed.

Briefly, some of the most consequential points deduced from our data on fresh articular cartilage were:

1. The total water content of the tissue decreased in amount from 80 per cent to 75 per cent as the puppies aged.

2. The connective tissue increased in amount from a value of 104 grams per kilogram to 159 grams per kilogram as the puppies aged while the chondroitin sulfate mass decreased from thirty-eight grams per kilogram to twenty-three grams per kilogram. Even though the chondroitin sulphate decreased, the connective tissue increased enough to bring up the mass of the total extracellular solids from a value of 146 grams per kilogram to 181 grams per kilogram.

3. The percentage of water in the chondrocytes was an average of 83 per cent through the sixteen-week-old group; thereafter it was an average of 75 per cent in the older groups.

4. The average concentration of potassium in the chondrocytes was fifty-three milliequivalents per kilogram of chondrocytes or sixty-six milliequivalents per kilogram of chondrocyte water. The average concentration of magnesium was thirty-five milliequivalents per kilogram of chondrocytes and forty-three milliequivalents per kilogram of chondrocyte water.

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Biochemical Studies of Articular Cartilage

II. Values following the Denervation of an Extremity*

BY WAYNE H. AKESON, M.D.**, LILLIAN EICHELBERGER, PH.D., AND MICHAEL ROMA, CHICAGO, ILLINOIS

From the Division of Orthopaedic Surgery and the Department of Biochemistry, the University of Chicago, Chicago

This study of the biochemical changes in articular cartilage in denervation atrophy is an extension of parallel work on skeletal muscle [9]. Our hope is that such biochemical examination of cartilage will open up a clearer prospect of what happens to the tissues of an extremity when it is denervated. Knowledge of cartilage changes in denervation atrophy to date has been confined to histological observation; we seek to provide quantitative histochemical patterns of the changes in cartilage in denervation atrophy. The study consequently supplies a comparison of the histochemical patterns of cartilage from the denervated hind extremity of puppies with those from the normal opposite weight-bearing extremity.

The puppies from which the cartilage specimens were obtained were bred by us in special metabolism cages. The puppies were weaned at eight weeks of age and were then fed four times a day with a standard commercial dog food supplemented with milk. At a specified age, the puppies were subjected to a left rhizotomy of the roots of the lumbosacral plexus through a left hemilaminectomy exposure. The hind limbs of the dog are innervated from the lumbosacral plexus representing spinal levels from the fourth lumbar through the second sacral. Complete denervation therefore was obtainable by taking two nerve roots higher and one root lower than the normal levels of supply of the hind extremity in order to obviate the possibility of innervation from an anomalous level. The opposite limb, innervated and weight-bearing, supplied the control cartilage.

At different ages the puppies were killed to obtain the cartilage from the joints of the control limb and from the denervated limb. The length of time of denervation ranged from four weeks to thirteen weeks, and the puppies ranged in ages from eleven to twenty-five weeks. Many of the puppies were litter mates.

The general techniques employed for the removal of the serum and the cartilage from the joints and the preparation of the tissue for chemical analyses, as well as the chemical methods have been described in detail in preceding papers [8, 10, 11].

In the present experiment in the analysis of the serum, the amounts of water, chloride, sodium, potassium, and total nitrogen were determined; in the analysis of the cartilage, the amounts of water, chloride, collagen nitrogen, and sulphate were determined. When a sufficient amount of cartilage was obtained, sodium and potassium determinations also were carried out. The amount of articular cartilage obtainable from the denervated extremity usually was only about 75 per cent of the amount obtainable from the weight-bearing limb.

The experimental work included in this paper was carried out at the same time as that reported in the previous paper of this series [11]. The symbols and calculations used here are the same as those employed and outlined in that paper.

RESULTS

The original data obtained from the analyses of serum and cartilage from eighteen

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** Fellow, the National Foundation for Infantile Paralysis.

TABLE I *†

MEAN VALUES FOR ARTICULAR CARTILAGE FROM PUPPIES

	Post-operative (*Weeks*)	Original Data						
		(H_2O) (*gm.*)	Cl (*meq.*)	Na (*meq.*)	K (*meq.*)	Total N (*gm.*)	Collagen N (*gm.*)	CSA (*gm.*)
Group I: (3)								
11–13 weeks of age	4							
Serum		951.1	115.9	145.3	4.64	7.86		
Standard deviation		0.3	1.0	1.7	0.20	0.13		
Control cartilage		795.1	36.1	104.3	15.1	12.6	8.5	17.8
Standard deviation		7.7	5.7	1.6	3.4	0.4	0.2	2.2
Denervated cartilage		815.0	46.2	97.8	15.1	13.0	8.6	14.1
Standard deviation		9.7	7.9	3.4	4.8	0.2	0.5	0.9
Group II: (5)								
14–17 weeks of age	5–8							
Serum		929.5	110.9	146.3	5.03	8.66		
Standard deviation		7.2	2.7	4.3	0.36	1.20		
Control cartilage		776.7	34.38	100.3	9.65	13.0	8.9	15.3
Standard deviation		11.0	5.0	7.7	1.6‡	0.6	0.5	1.7
Denervated cartilage		801.3	39.52	92.6	9.31	13.2	8.9	12.6
Standard deviation		10.0	5.5	6.0	0.89	0.6	0.4	1.5
Group III: (5)								
18–20 weeks of age	8–9							
Serum		930.1	110.2	146.6	5.11	8.31		
Standard deviation		2.9	0.4	1.4	0.13	0.36		
Control cartilage		753.4	27.6	75.4	8.40	13.5	8.80	12.2
Standard deviation		8.5	4.2	7.2	0.5	0.6	0.7	1.2
Denervated cartilage		791.4	38.2	78.0	8.40	13.5	8.80	8.9
Standard deviation		11.9	2.4	4.7	0.3	0.4	0.5	1.5
Group IV: (5)								
22–25 weeks of age	8–12							
Serum		928.2	109.2	141.9	4.84	9.72		
Standard deviation		1.9	1.0	3.2	0.18	0.36		
Control cartilage		752.1	28.11	77.7	8.40	13.3	9.1	10.6
Standard deviation		18.0	1.60	10.0	1.2	0.4	0.5	1.9
Denervated cartilage		766.6	34.80			12.9	8.8	9.9
Standard deviation		22.0	2.7			0.4	0.1	2.6

* Serum values are given in units per kilogram of serum.
† Cartilage values are given in units per 100 grams of cartilage solids except water values which are given in grams per kilogram wet weight.

puppies in which one hind extremity had been denervated are presented in Table I. The puppies were grouped primarily according to age and secondarily according to the length of time of the denervation of the extremity. This method of grouping was used because the chemical changes in the tissue appeared rapidly at first, progressed, and then seemed to remain somewhat stationary. First the control values are given, followed by the values from the denervated limb. Four groups are presented with means and standard deviations for each group.

The major changes observed by direct chemical analyses of a block of the cartilage of the denervated limb as compared with data from the control limb (Table I) were: (1) a marked increase in the total water content, and (2) lower values of chondroitin sulphate. This increase in the total water content evidently was the result of a larger

extracellular-water volume, indicated by the considerable increase in the total determined chloride content [1] from 15 to 40 per cent in all of the groups. The chondroitin sulphate values were from 7 to 27 per cent less on the denervated side.

The original chemical data were interpreted histochemically in order to estimate

TABLE II *

HISTOCHEMICAL DATA FOR ARTICULAR CARTILAGE SOLIDS

Estimated Weight of Extracellular ($E)_s$ and Intracellular ($C)_s$ Solids in 100 Grams of Cartilage Solids

Group	Age (*Weeks*)	Post-operative (*Weeks*)	$(E)_s$ (*gm.*)	$(C)_s$ (*gm.*)	$(F)_s$ (*gm.*)	CSA_s (*gm.*)	Wgt. Δ Na_s (*gm.*)
I.	11–13	4					
Control cartilage			74	26	54	18	2
Denervated cartilage			70	30	54	14	2
II.	14–17	5–9					
Control cartilage			73	27	56	15	2
Denervated cartilage			71	29	56	13	2
III.	18–20	8–9					
Control cartilage			69	31	56	12	1
Denervated cartilage			66	34	56	9	1
IV.	22–25	8–12					
Control cartilage			69	31	57	11	1
Denervated cartilage			67	33	56	10	1

* Subscript small s refers to 100 grams cartilage solids.
$(E)_s = (F)_s + CSA_s + \text{Wgt. } \Delta\ Na_s$
$(C)_s = 100 - (E)_s$

TABLE III *

PHASE MASS DATA FOR ONE KILOGRAM OF ARTICULAR CARTILAGE DERIVED SOLIDS

Group	Total Water (*gm.*)	Total Solids (*gm.*)	$(F)_S$ (*gm.*)	CSA_S (*gm.*)	Wgt. Δ Na_S (*gm.*)	$(E)_S$ (*gm.*)	$(C)_S$ (*gm.*)
I.							
Control cartilage	795	205	110	36.5	4.3	151	54
Denervated cartilage	815	185	100	26.1	3.7	130	55
II.							
Control cartilage	777	223	125	34.1	4.2	163	60
Denervated cartilage	801	199	111	25.9	3.6	141	58
III.							
Control cartilage	753	247	138	30.1	3.7	172	75
Denervated cartilage	791	209	117	18.8	3.1	139	70
IV.							
Control cartilage	752	248	141	26.3	3.7	171	77
Denervated cartilage	767	233	130	23.0	3.5	156	77

* Subscript capital S refers to one kilogram of fresh cartilage.
$(E)_S = (F)_S + CSA_S + \text{Wgt. } \Delta\ Na_S$
$(C)_S = \text{Total solids} - (E)_S$

the proportion of extracellular and intracellular compartments in the whole tissue. This separation of cartilage into compartments was necessary because of the great difference between the composition of the chondrocytes and their immediate environment. Because of this difference a change in the relative amounts of these compartments could cause marked changes in the chemical composition of the whole tissue. Therefore by plotting the masses of the two separate compartments instead of considering the whole tissue, a clearer definition could be acquired of the chemical events which follow atrophy from denervation.

In Tables II, III, and IV are the derived histochemical data or the quantitative

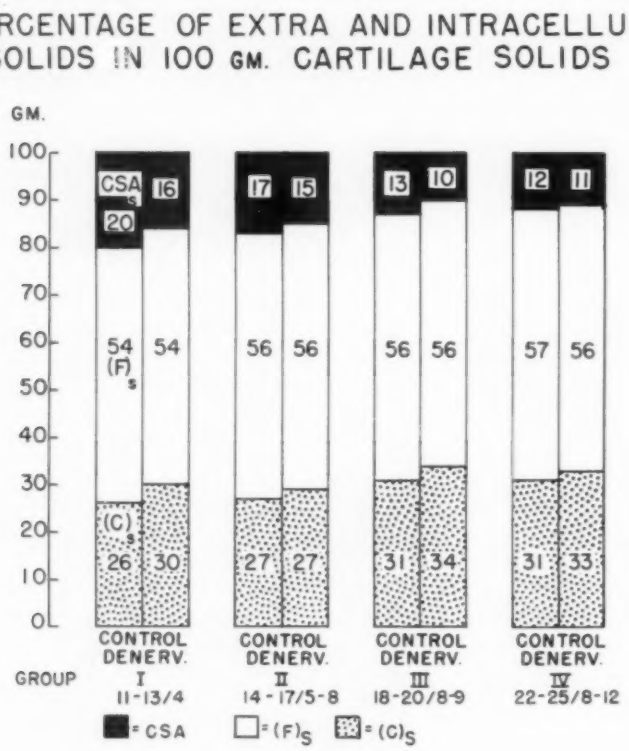

CHART 1

measurement of the relative amounts of the various phases of this tissue. Since our chemical work was done on cartilage solids, we will consider the partition of 100 grams of cartilage solids into extracellular solids $(E)_s$ and intracellular solids $(C)_s$. We have noted previously that the extracellular solids of cartilage are composed of connective-tissue solids $(F)_s$ plus the chondroitin sulphate solids $(CSA)_s$ plus the weight of sodium that is not associated with the connective-tissue fibers $(\Delta\ Na)_s$; the chondrocyte solids are obtained by difference [7]. Table II shows the assembled data for such calculations, and it will be noted that the mass of the extracellular solids decreased in the cartilage from the denervated limb which is the result solely of a loss of chondroitin sulphate mass. These data are graphically shown in Chart I.

From the original data and the description of the relative amounts of extracellular solids and cellular solids in 100 grams of total cartilage solids (Table II) the mass of the

TABLE IV *

PHASE MASS DATA FOR ONE KILOGRAM CARTILAGE
DERIVED WATER

	$(F)_S$ (gm.)	$(H_2O)_F$ (gm.)	$(Cl)_F$ (meq.)	$(Cl)_S$ (meq.)	ΔCl_S (meq.)	Cl_U (meq.)	$(H_2O)_U$ (gm.)	$(H_2O)_E$ (gm.)	$(E)_S$ (gm.)	$(H_2O)_C$ (gm.)	$(C)_S$ (gm.)	$\{H_2O\}_C$ (gm.)
Group I.												
Control cartilage	110	173	22.7	74.0	51.3	127.0	404	577	151	218	54	801
Denervated cartilage	100	157	20.6	85.5	64.9		504	661	130	154	55	737
Group II.												
Control cartilage	125	196	25.8	76.7	50.9	124.1	410	606	163	171	60	741
Denervated cartilage	111	174	22.9	78.6	55.7		449	623	141	178	58	754
Group III.												
Control cartilage	138	217	28.5	68.2	39.7	123.3	323	540	172	213	75	740
Denervated cartilage	117	184	24.2	79.8	55.6		452	636	139	155	70	689
Group IV.												
Control cartilage	141	221	29.1	69.7	40.6	122.3	332	553	171	199	77	721
Denervated cartilage	130	204	26.8	81.1	54.3		444	648	156	119	77	607

*$(H_2O)_E = (H_2O)_F + (H_2O)_U$
$(H_2O)_C$ = Total water $- (H_2O)_E$
$\{H_2O\}_C = (H_2O)_C \times 1000/(H_2O)_C + (C)_S$

extracellular phases and the intracellular phases per kilogram of fresh cartilage can be derived. Table III gives the derived mass of extracellular solids (E) and the derived mass of chondrocytes solids $(C)_S$ per kilogram of fresh cartilage. The extracellular solids consisting of connective-tissue solids $(F)_S$ plus chondroitin sulphate solids $(CSA)_S$ plus the weight of sodium not associated with the connective tissue $(\Delta Na)_S$, from the cartilage of the denervated extremity were smaller in amount in all groups when compared with those from control cartilage. This decrease is the result of a fall in the chondroitin sulphate mass and a small decrease in the mass of connective-tissue solids.

In Table IV are the derived water values per kilogram of fresh cartilage. The extracellular water $(H_2O)_E$, which is the combined water associated with the connective tissue $(H_2O)_F$ plus the ultrafiltrate water $(H_2O)_U$, increased in volume in all of the denervated tissue. At the same time the water of the chondrocytes decreased in volume but not enough to account for all of the gain in the extracellular water. It will be noted that the gain in the extracellular water was the result of the increase in the volume of the ultrafiltrate water. The water associated with connective-tissue fibers actually decreased in volume because the weight of the connective-tissue-fiber solids decreased in amount following the denervation which in turn was the result of the diluting effect of the increased volume of ultrafiltrate water per kilogram of tissue. Graphic representa-

tion for the patterns of one kilogram of fresh cartilage from both the control and the denervated limbs is presented in Chart II.

DISCUSSION

To attempt to understand what takes place in joint cartilage following the denervation of an extremity, we need to know not only the changes that occur in the mass of the phases of the tissue but also the chemical composition of the phases and the changes which occur in the efficiency with which the systems work. In an organized tissue such as cartilage, the tissue cells are surrounded by a fluid environment which contains many different kinds of microscopic fibers in the extracellular compartment. Whether these

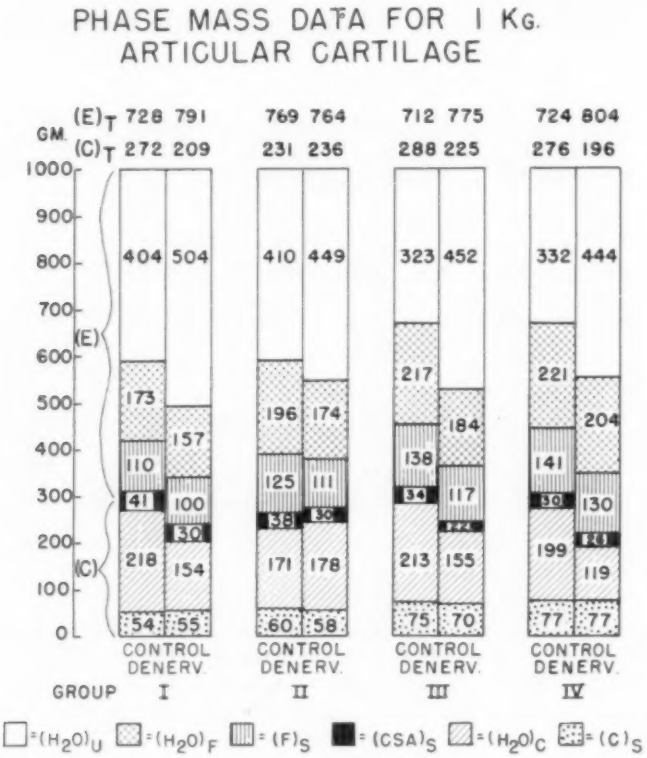

CHART II

fibers in this compartment are formed by the extracellular fluids themselves or by the cartilage cells under the influence of the extracellular fluids is not known at present. Wolbach [14], in 1933, working with collagen fibers came to the conclusion that they were formed from secretion elaborated by the fibroblasts and discharged by them into the extracellular fluid. More recently, Dunphy and Udupa have postulated that fibroblasts produce a soluble protein procollagenous substance which precipitates collagen fiber in the presence of a carbohydrate fraction in the ground substance.

It is clear that one of the most characteristic activities of normal living cells is the ability to maintain within cell boundaries a chemical composition differing from that of the external medium. Particularly important and selective in cartilage is the ground substance in the extracellular compartment, and therefore all factors that might influence

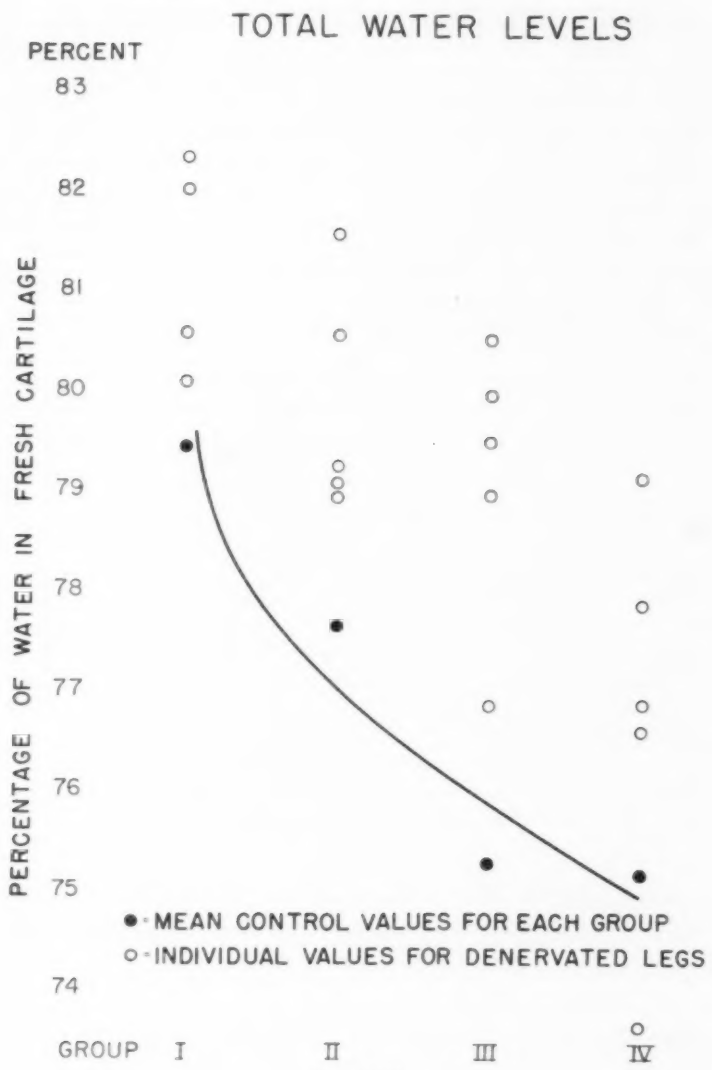

CHART III

the concentration of the chemical components in this ground substance, as well as in the chondrocytes, should be examined.

In chemical analysis of cartilage tissue, young animals have to be used. Following the atrophy of cartilage about 25 per cent less of the tissue is obtainable from the denervated joint than from the control joint. The limited amount of material available therefore restricts the number of analyses that can be carried out on the denervated cartilage. Since the histochemical change with age has been presented in a previous paper [11] it will not be discussed here. We are only concerned with the change between the values of the control limb and the denervated limb which represents the change resulting from atrophy following denervation.

Probably one of the most important findings was the volume increase in total water content of cartilage following atrophy. In Chart III the curve represents the total water

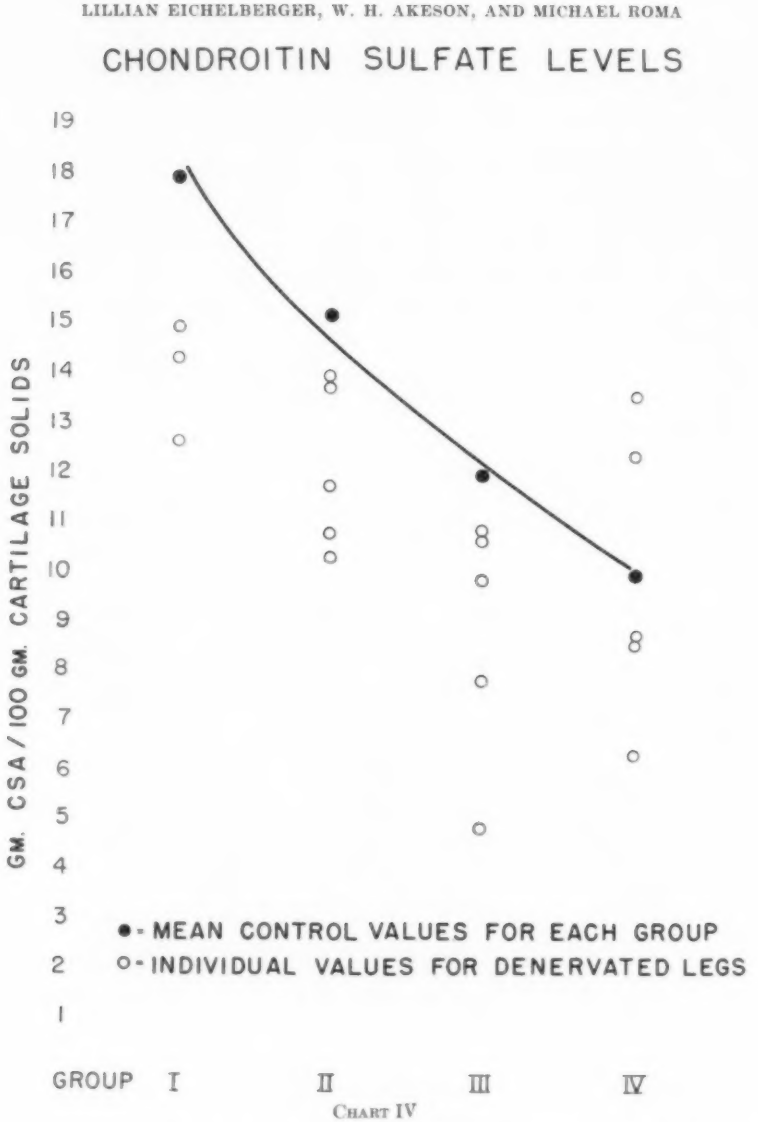

CHART IV

content in percentage of the control cartilage as the puppies increase in age. The individual small circles represent the individual values obtained from the cartilage from the denervated leg. From Table IV and Chart III, it is clearly shown that this increase in water is entirely the result of increase in the ultrafiltrate water in the extracellular compartment of the tissue. This is consistent with the finding obtained on skeletal muscle in atrophy following denervation [9]. The increase in the volume of extracellular fluid in cartilage assuredly has decided effects on the transport of materials to the chondrocytes as well as the removal of waste products. Nutrition of the chondrocytes may be affected by the large increase in distance between the cells and their surrounding media.

Another change in the extracellular compartment, which is characteristic of cartilage in an atrophic extremity, was the decrease in the mass of chondroitin sulphate. In Chart IV, the curve represents the chondroitin sulphate mass per 100 grams of control cartilage

solids as the puppies increase in age. The individual small circles represent the individual values obtained from the cartilage from the denervated leg. In atrophy, therefore, the mass of the chondroitin sulphate decreases whether the amount in 100 grams of cartilage solids (Table II) or in a kilogram of fresh cartilage is considered (Table III). This shows that the low chondroitin sulphate concentration is obviously not the result entirely of dilution of the extracellular compartment.

It is most interesting that the low chondroitin sulphate content found in cartilage from a denervated extremity is phenomenonally similar to the chondroitin sulphate values found in the hyaline cartilage removed from the joint surfaces of poliomyelitic patients at the time of various reconstructive procedures [6]. The low content of chondroitin sulphate of hyaline cartilage from poliomyelitic patients, which was previously unaccounted for, now may be said to be attributable to the result of the denervation atrophy caused by the disease.

The loss in chondroitin sulphate could have occurred as the result of decreased production of this substance, or possibly an accelerated breakdown of the long polysaccharide molecules. While at present there is no positive explanation for the low chondroitin sulphate, there is prospect that the studies of a number of investigators[3,12,13] may aid us later in establishing the reason for these low values.

The rapidity with which the changes occurred in the experimental cartilage is of some interest. The degree of change which was apparent at the end of four weeks of denervation was nearly as great as that which occurred in animals not examined until the end of twelve weeks of denervation. This suggests the possibility that a higher rate of metabolism exists in cartilage than is generally realized. This is supported by the recent work of Boström who worked with S^{35}.

After drawing attention to the changes in the extracellular compartment, we must consider the intracellular compartment. Whether the cells of a tissue are what the extracellular fluids make them has been fully discussed by Cowdry.[4] Furthermore, there is a possibility that the tissue cells produce tissue fluids in accordance with classical patterns selective to an individual tissue. Therefore, for the intracellular phase (chondrocytes), we have presented the water content and solids of this phase. The water content of these cells is of primary functional importance. It is shown here that the percentage of water in the chondrocytes decreased from an average normal percentage of 80 to 74 in the young puppies (Group I) with only four weeks of atrophy; in the older puppies with up to twelve weeks of atrophy the percentage of cell water decreased from 74 in the control to as low an average as 60 in the cartilage with atrophy. The function of a cell may be altered by the amount of functioning cytoplasm.

It is probable, therefore, that in a tissue such as cartilage, there is a stable relationship between the mass of the extracellular and intracellular phases, and deviations from this relationship in either direction may result in major disturbances in the metabolic activity of the chondrocytes. Without doubt we have presented many of these major disturbances in articular cartilage in atrophy following denervation of an extremity. Other forms of experimental atrophy must now be produced in order to determine if the changes presented here are reversible during the growth period of an animal when cartilage shows its greatest power of activity.

SUMMARY

The histochemical characterization of articular cartilage from the joint surfaces of the hind limbs of puppies up to twenty-five weeks of age and twelve weeks following the denervation of one extremity was examined. The animals were divided into four groups, primarily according to age and secondarily according to the length of time following the denervation. The chemical changes occurring in the atrophied tissues appeared rapidly at first, progressed, and then seemed to remain somewhat stationary. In all of

the groups, the extracellular-solid mass decreased as a result of some decrease in the connective-tissue solids and a marked decrease in the chondroitin sulphate. The extracellular water increased markedly as a result of large increases in the ultrafiltrate water. The water of the chondrocytes (the intracellular water) decreased in volume as well as in percentage.

Some of the salient points gathered from observations on articular cartilage which had atrophied following denervation of the extremity were:

1. An increase in total water content of the cartilage, resulting from increases in the ultrafiltrate water in the extracellular compartment of the tissue;

2. A marked decrease in the chondroitin sulphate mass (not only was the decrease found when 100 grams of the cartilage solids was considered but also when a kilogram of fresh cartilage was considered);

3. A decrease in the connective-tissue mass expressed per kilogram of fresh tissue, which was the result of dilution of the extracellular compartment with large volumes of ultrafiltrate water;

4. Percentage of water in the chondrocytes decreased in value from an average normal of 80 to 74 in the young puppies with four weeks of atrophy following denervation and from 74 in the controls to as low as 60 in the older puppies with up to twelve weeks of atrophy.

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Electron Microscopy of Epiphyseal and Articular Cartilage Matrix in the Femur of the Newborn Infant*

BY D. A. CAMERON, M.D.S.** AND ROBERT A. ROBINSON, M.D., BALTIMORE, MARYLAND

From the Division of Orthopaedic Surgery, The Johns Hopkins University Medical School, Baltimore

In a previous paper [6], it was noted that the fibrils of the epiphyseal cartilage at the distal end of the femur in newborn infants were different from those in the neighboring bone. This difference was mainly one of size. A striking feature was that all the fibrils appeared to be narrow. The larger ones usually found in young collagenous tissue [2,5] were absent. The fibrils were also very loosely arranged. These observations of the epiphysis have been extended to the articular surface and it has been found that the fibrils in this region are larger, are more closely packed, and are formed into obvious bundles similar to those in other fibrous tissue and in bone.

MATERIALS AND METHODS

The tissue was obtained from the distal end of the femora of infants who died in the neonatal period. The methods of collecting and processing the tissue have already been described [6]. The sections were cut from the articular surface, the intermediate zone, the proliferative zone, the hypertrophic zone, and the degenerative zone (Figs. 1 and 2).

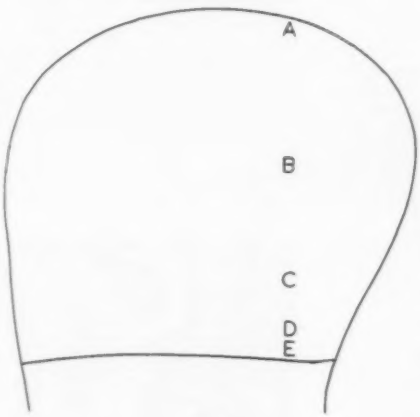

FIG. 1

Diagram of the distal end of the femur: *A*, articular surface; *B*, intermediate zone; *C*, proliferative zone; *D*, hypertrophic zone; and *E*, degenerative zone.

OBSERVATIONS

General

Throughout the epiphyseal cartilage the cells are surrounded by an extracellular matrix which is not of uniform density. There is a moat around the cells which is particularly prominent in the proliferative, hypertrophic, and degenerative zones and which contains amorphous material mixed with a few fibrils. These moats may be artifacts. If, however, they are artifacts, they are consistent artifacts in the zones of maturing cartilage. The cartilage cell may completely fill the whole space in the matrix when it is producing matrix, and only when it stops producing does it pull away from the matrix or shrink. Another possibility is that only certain cartilage cells have moats or show moats after fixation. There does not seem to be such a moat in ear cartilage of rabbits, and we did not find such a moat around the cartilage cell near the periphery of articular cartilage at the joint surface. Between the moats the fibrils are much more numerous and the change in concentration is fairly sharp. In some places the fibrils in the matrix adjacent to the moats are more closely packed than are those at a greater distance.

The internal structure of the cells in the moats will not be described as no structures have been observed of sufficient significance to outweigh the considerations of possible

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** Supported by grants from the Fulbright and the United States Information and Education Exchange (Smith-Mundt) Acts.

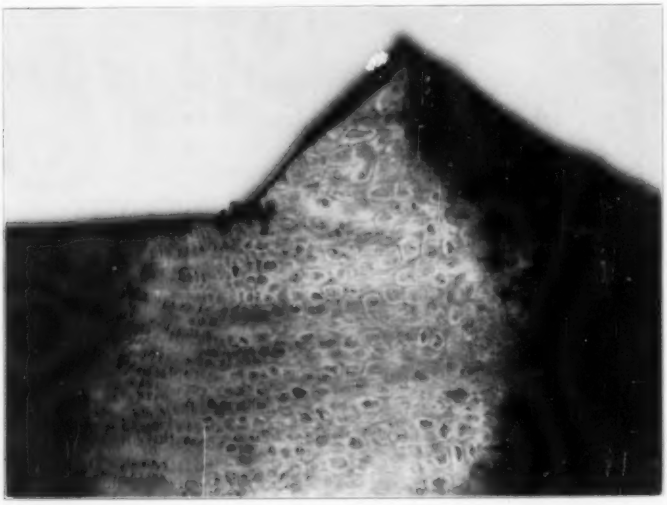

FIG. 2

A light photomicrograph of epiphyseal cartilage of the rat. The section is a vertical one through the epiphyseal apparatus. At one end of the section (left) is seen the proliferative zone and at the other end of the section (right) the area of cell hypertrophy and degeneration and cartilage matrix calcification is observed. The piece of tissue is so cut that a wedge protrudes at one side of the section and it will be noted that the peak of the wedge is at the top level of the zone of cartilage calcification. Such a specimen when mounted in the microtome in which sections for electron microscopy are cut would be so positioned that the glass knife shaves off small sections starting at the apex of the wedge. If this wedge or pyramid is placed at a higher level in the epiphyseal apparatus, sections at its apex would show cartilage cells and matrix in the articular zone, intermediate zone, or the proliferative zone depending on the level of the wedge.

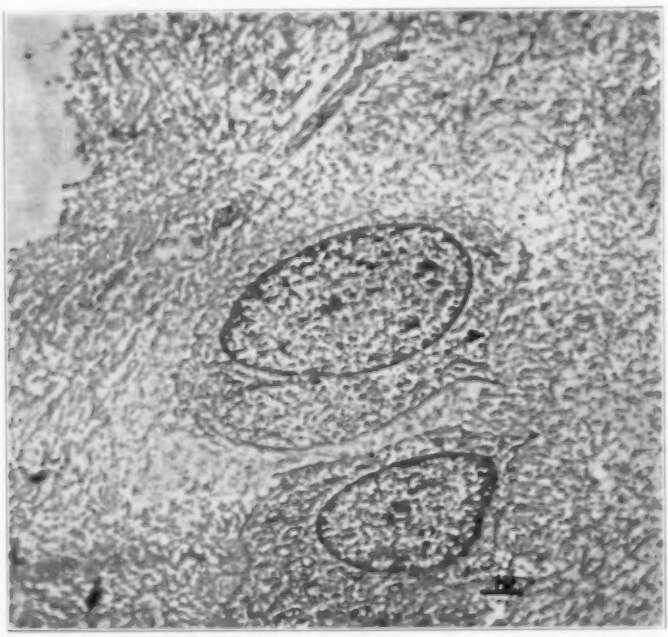

FIG. 3

The articular surface layer. Part of the joint cavity is at the top left-hand corner of the picture. Bundles of fibrils cut at various angles can be seen (× 6,500).

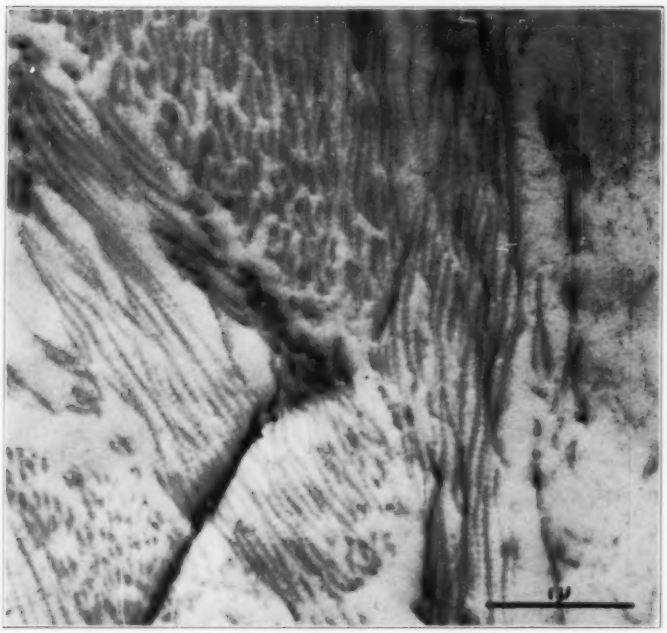

FIG. 4

Bundles of fibrils in the articular surface layer. The collagen periodicity is quite prominent and the fibrils are up to 500 Angstrom units wide (× 23,000).

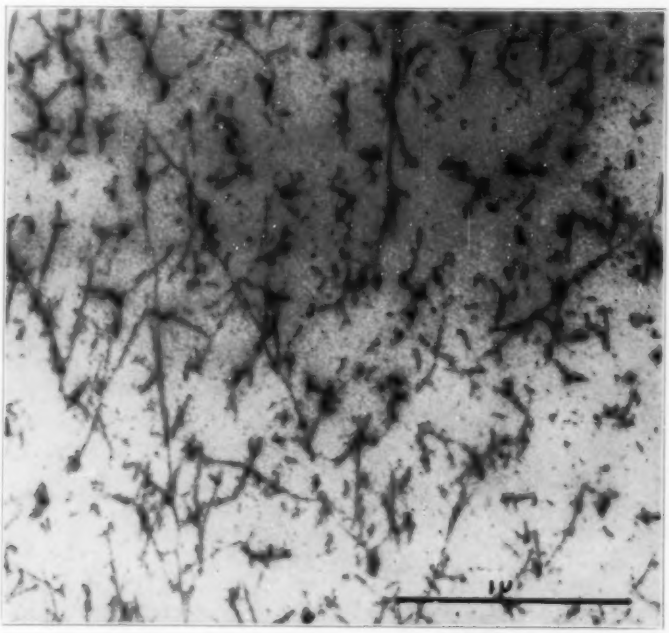

FIG. 5

Intermediate zone. The fibrils are much narrower than those in Fig. 4 and are quite widely separated (× 36,000).

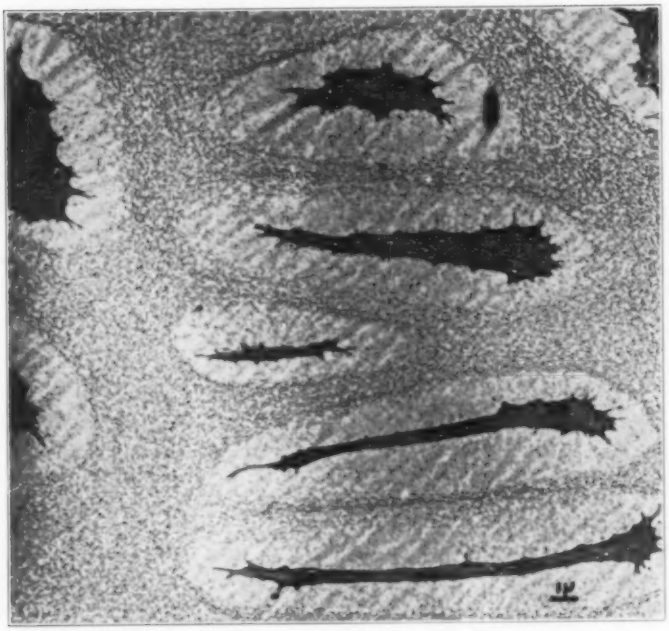

FIG. 6

Proliferative zone. Each cell is surrounded by a moat which contains amorphous and a small amount of some fibrillar material. There is very little suggestion that the fibrils of the matrix form bundles (× 4,120) (R. A. Robinson and D. A. Cameron, Clinical Orthopaedics, No. 9, p. 16, 1957).

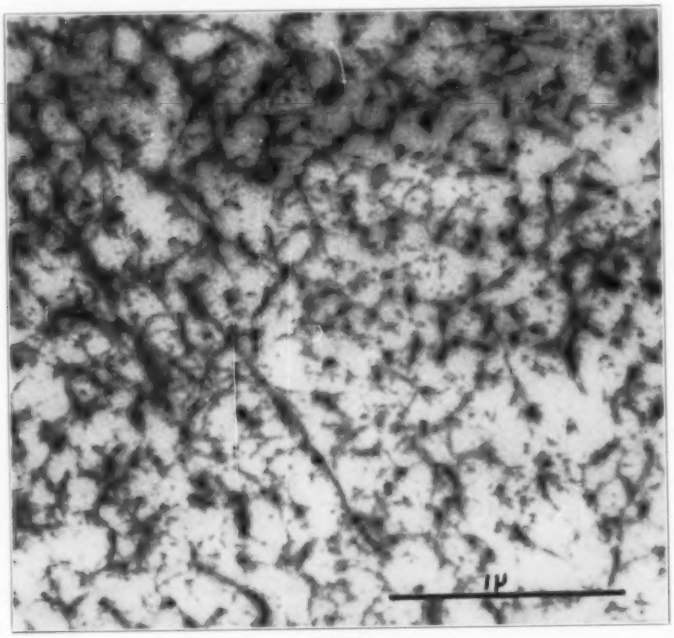

FIG. 7

The loose network of fine fibrils in the proliferative zone (× 36,000).

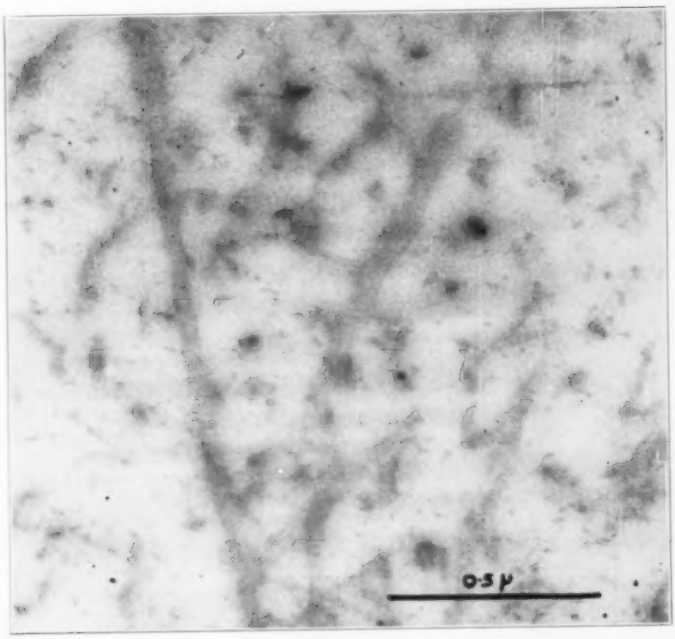

FIG. 8

Proliferative zone. Fibrils as wide as these are occasionally found, but the majority are much narrower. No cross striations are visible in these large fibrils and the possibility of their being intercellular tubules should be considered (× 66,000).

cytoplasmic postmortem change. Their stellate shape which suggests the possibility of extensions of the cytoplasm into the matrix should be noted.

The Articular Surface (Figs. 3 and 4)

There do not appear to be any cells covering the surface although at intervals cells resembling those in the underlying tissue are exposed upon it. The fibrils are 250 to 500 Angstrom units in diameter, have the characteristic collagen period, and many of them are grouped into bundles (fibers). This zone of grouped fibrils is quite narrow and is only present for a width of 250,000 Angstrom units (twenty-five micra) or less beneath the surface. They tend to lie parallel to the joint surface, whereas those deeper in the epiphysis tend to have their long axes vertical to the joint surface. This general trend of fibril orientation at the joint surface can be demonstrated by polarized light in the light microscope.

The Intermediate Zone (Fig. 5)

The intermediate zone which occupies the major part of the epiphysis has a matrix in which fine fibrils measuring about 100 to 250 Angstrom units in diameter lie more widely separated. Electron micrographs of this tissue show fibrils that appear to branch but this is an illusion, the result of superimposition of fibrils running obliquely through the thickness of the section. These fibrils appear, at the level of organization observed in the electron microscope, to run in all directions and rarely form bundles as at the articular surface. It is in this zone that the osseous epiphyseal center appears later in life.

The Proliferative Zone (Figs. 6, 7, and 8)

The average fibril size is similar to that in the intermediate zone. Because of variations in section thickness it is not possible to be sure that the fibrils are more closely packed

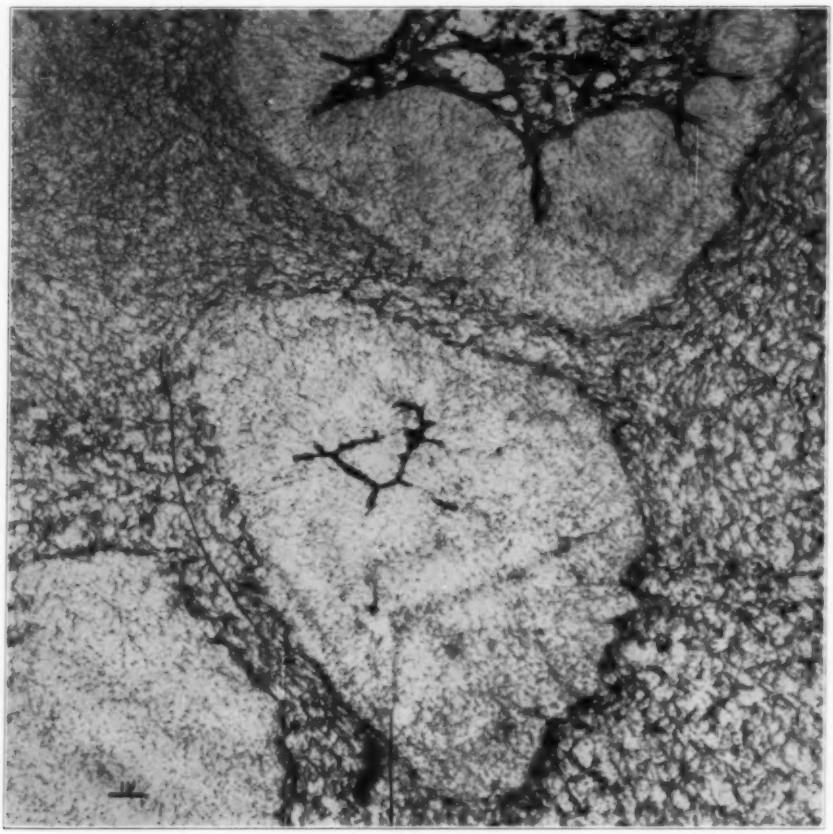

FIG. 9

The hypertrophic and degenerative zones. The capsules or moats around the cells are enlarged. One contains a swollen cell and another the remnants of one. This is a thick section but the fine fibril network can still be seen (× 5,370).

here than in the intermediate zone although this may be the case. Occasional fibrils are larger than the majority, up to 500 Angstrom units in diameter, and while not showing any periodic structure their margins are quite clearly defined (Fig. 8). The fact that they have no periodic band pattern has raised the question of their being tubules.

The Hypertrophic and Degenerative Zones (Figs. 9 and 10)

There is more indication here of the fibrils running parallel to one another, although bundles like those at the articular surface are not seen. The fibrils are still narrow and well separated, but many of them appear to run in pairs. More prominent in this zone than elsewhere are circular structures with an electron dense border and measuring up to 500 Angstrom units in diameter (Fig. 10). This would suggest cross sections of the larger fibrils rarely found in the proliferative zones although no such large fibrils have been found running in the plane of the sections in these zones. An exact understanding of these circular structures is lacking at present, but the possibility of a canalicular system between cartilage cells is suggested.

DISCUSSION

These observations show a difference between the extracellular cartilage matrix in

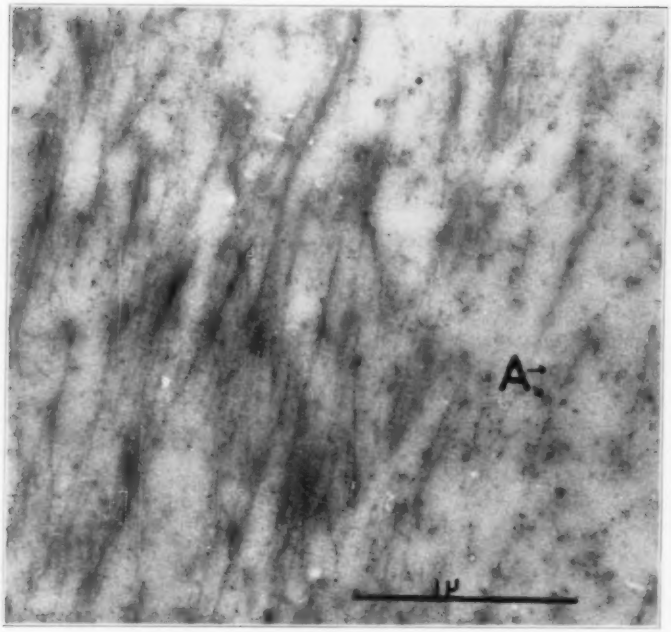

FIG. 10

The degenerative zone. Fine fibrils without obvious cross striations. At *A* are some circular objects suggesting cross sections of fibrils about 500 Angstrom units in diameter (× 34,500).

the articular surface and that in the rest of the epiphysis of the newborn infant. At the surface, the fibrils have the classic periodicity of collagen and are arranged in bundles which would make up the fibers of Benninghof's arcades seen in this region with the light microscope. In the bulk of the epiphysis the fibrils are more widely spaced, are considerably smaller in diameter, and lack the characteristic periodicity of collagen. It is possible that these fine fibrils are reticulin fibrils but there is no general agreement about the difference between reticulin and collagen. The presence of birefringence in this cartilage at all levels and the suggestion of periodicity reported by Martin makes us hesitate to say that the fibrils are not collagenous.

The fact that most of the fibrils are smaller in diameter and fail to show a definite band pattern does not mean that they are not made up of the same chemical units of which more classical collagen fibrils are composed. Gross has shown that, depending on its environment, collagen in solution can be reconstituted into structures which have a variety of appearances in the electron microscope. Histologically this epiphyseal cartilage matrix is similar to cartilage matrix in other sites some of which (nasal cartilage, for example) in the dry state has been shown to be composed almost entirely of collagen and chrondroitin sulphate [4].

SUMMARY

The cartilage at the distal end of the femur in newborn infants is divided into two structurally different units.

The matrix at the articular surface contains bundles of fibrils which are 250 to 500 Angstrom units in diameter and have the periodic structure of collagen. They end abruptly on the joint surface and do not appear to be covered by a membrane of acellular or cellular matter.

In the matrix of the remainder of the cartilage the fibrils are much less densely packed and show slight tendency to form fiber bundles. In this loose network almost all of the fibrils are less than 250 Angstrom units in diameter. In these fibrils no periodic structure has been demonstrated regardless of the staining method employed with both phosphotungstic and osmic acids.

Occasional large fibril-like structures without evident periodic banding found in the matrix of the proliferative zone, circular structures in the zone of degenerating cartilage cells, and the stellate prolongations of the periphery of some cartilage cells out to the matrix only suggest the possibility of protoplasmic extensions of the cells into the matrix.

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Kinetics of Strontium Metabolism in Man * †

BY GÖRAN C. H. BAUER, M.D., MALMÖ, SWEDEN, AND ROBERT D. RAY, M.D., SEATTLE, WASHINGTON

From the University of Lund, Department of Orthopaedics, Malmö, and the Division of Orthopaedic Surgery, University of Washington Medical School, Seattle

INTRODUCTION

This is a study of the metabolism of strontium in human subjects. Results of previous investigations indicate that the skeletal metabolism of strontium in trace amounts in rats [3] and man [24, 26] closely parallels that of calcium although the excretory mechanisms distinguish between the two elements. Hence, it appeared that strontium might prove useful as a tracer for calcium in studying certain aspects of skeletal metabolism in man, particularly since one isotope, Sr^{85}, with a half-life of sixty-five days, has a pure gamma-ray emission which should permit surface counting over the body. Another factor prompting this study is that further knowledge of strontium metabolism in man should be of value since another radioactive isotope of strontium, Sr^{90}, produced by nuclear fission, is regarded as a serious potential health hazard [10].

In this investigation, in addition to surface-counting, analysis was made of the activity of blood, urine, and faeces following administration of Sr^{85} to five essentially normal adult subjects. The results were analyzed with an electronic analogue computer. This method for analysis of isotope data has previously been of advantage in studies of iodine [25], iron [16], and calcium [19] metabolism.

MATERIAL AND METHODS

The series is comprised of five ambulatory men who were hospitalized for other causes during the study. All patients were in good general condition at the time of the study. Their intake, food as well as drink, was not restricted.

SUBJECT 1. W. J., a white man, thirty-three years old, and weighing 173 pounds, had a comminuted fracture of the right calcaneus three months prior to the isotope investigation. At the time of investigation the patient could walk with a cane although he had signs of vasomotor disturbance and roentgenograms showed loss of density in the skeleton of the affected right foot.

SUBJECT 2. R. H., a white man, forty-five years old and weighing 185 pounds, had a rotational osteotomy of the left tibia two weeks prior to the isotope investigation. Internal fixation was carried out with plate and screws, and the limb was immobilized in a toe-to-groin cast.

SUBJECT 3. J. K. was a white man, twenty-four years old, who was injured by a revolver bullet in the lumbar spine seven months prior to the isotope study. He weighed 155 pounds. Due to damage to the cauda equina the patient had loss of function and hypaesthesia of the left leg necessitating the use of a cane.

SUBJECT 4. S. L., a white man, twenty-three years old, had a comminuted fracture of the right mid-femur following a car accident two years prior to the isotope investigation. He weighed 205 pounds. A spontaneous fracture of the osteoporotic lower one-third of the right femur occurred seven months prior to the isotope study. This was treated with immobilization and Russell traction. At the time of the investigation the patient had started to walk with a cane and wore a toe-to-groin brace.

SUBJECT 5. J. S., a white man thirty-five years old, had an arthrodesis of the left shoulder joint to correct recurrent dislocation. At the time of the isotope investigation, six weeks following operation, the patient was still immobilized in a thoracic spica cast with the left arm in abduction. His weight was 185 pounds.

Carrier-free Sr^{85} ** in a solution of HCl containing more than 0.1 millicurie per milliliter was neutralized with Na_2CO_3, diluted with physiologic saline to an activity content of thirty microcuries per milliliter, and sterilized. Each patient was given a dose containing about thirty microcuries of activity. In four of the patients the injection was made intravenously. In one patient, Subject 2, the injection was inadvertently

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** Obtained from Nuclear Science and Engineering Corporation, Pittsburgh, Pennsylvania.

made perivenously. It was found by external counting that the half-life of the isotope at the injection site was approximately thirty minutes. This finding will be discussed later.

After the injection, blood samples were drawn at intervals from five minutes to seven days or more, and were transferred to centrifuge tubes and allowed to clot. The blood was then centrifuged and one to four milliliters of serum was transferred with a pipette into standard vials for counting in a scintillation well counter. Similar vials each containing a known amount of Sr^{85}, usually $\frac{1}{100}$ per cent of dose per milliliter, served as standards. The serum determinants were recorded in terms of per cent of dose per 2.5 liters of serum, the estimated serum volume of an average adult man.

Urine was collected quantitatively in polyethylene bottles. During the latter part of this investigation, the collection bottles used were large enough to hold all the urine collected in twenty-four hours. The activity of the urine was determined either by counting an aliquot of it in a well counter (using the same standards as for serum-counting) or by counting the entire sample in the polyethylene bottles placed on top of a scintillation detector. The standard in the latter case was a similar bottle containing a fraction of the dose (usually 2 per cent) and filled with water. A plot constructed from the counting rate of the standard *versus* the amount of water (recorded as height) made it possible to calculate the percentage of dose in the urine from the counting rate and height of urine in the bottle. In later studies, water was added to the sample in the collection bottle until the volume of urine plus water equaled the volume of water in the standard bottle. The urine-activity values were expressed in terms of percentage of the dose administered.

Quantitative stool collections for each patient were pooled and homogenized, and their activity determined either in the well counter by counting acid solutions of ashed aliquots or by counting an aliquot while it was being mixed in a Waring Blendor. By comparing this activity with that in a standard solution containing a fraction of the original dose per unit volume, the activity of each sample could be expressed in terms of percentage of the dose administered.

Body-surface counting was carried out at intervals following injection of the isotope with a collimated scintillation crystal placed over the patella, femur, and tibia. During the first half-hour continuous recordings were made in some instances. The following locations were routinely counted: one or both thighs (one hand's breadth proximal to the upper margin of the patella), one or both knees (with the knee extended, the patella fitting snugly into the collimation head of the detector), and one or both shins (one hand's breath distal to the tibial tuberosity). Two counts were always made over each area. Between counts the detector was repositioned. The error of the individual counts due to the random nature of radioactive decay was kept below 5 per cent. The background-counting rate was less than one-fifth of each count (usually considerably less than that) and was determined with the counter over the patient but with the sensitive area turned away from him. The counting rates were corrected for background and decay.

In some patients surface-counting over the trunk was carried out according to the technique of Huff and associates [15]. At each of six equally spaced levels (Fig. 2: upper level through the suprasternal notch, lower level through the pubic symphysis), eight equally spaced sites (0 degrees to 315 degrees) were counted by directing the collimated detector toward an imaginary body axis. At certain intervals of time following injection of the isotope each of forty-eight sites was thus counted. Four hundred counts or more were recorded for each site. The counting rates were corrected for background and decay. Additional counting areas were occasionally chosen and will be described.

RESULTS

Following intravenous injection of Sr^{85}, the serum activity rapidly dropped in five minutes to 20 per cent of the injected dose per 2.5 liters of serum, after one hour to about 10 per cent, after twenty-four hours to about 3 per cent, and by one week to about 0.5 per cent. The individual serum-activity values are recorded in Table I. In all patients it was found that one exponential adequately described the fall in serum activity from three days following administration of the isotope to the end of the experimental period, seven to fourteen days following injection. In each instance, starting with the tail end of the curve, graphic analysis [22, 23] of the serum data was made, the unit of volume being 2.5 liters and the unit of time one minute. The amount of isotope contained in the entire serum volume at any interval of time following administration of the isotope could be described by an equation of the following form with four exponentials:

$$B^* = A'_1 e^{-k'_1 t} + A'_2 e^{-k'_2 t} + A'_3 e^{-k'_3 t} + A'_4 e^{-k'_4 t}$$

The results of these analyses are given in Table II.

The daily urinary excretion of the injected dose decreased from about 20 per cent during Day 1 to about 0.5 per cent during Day 14. The rate at which strontium was

TABLE I

SERUM Sr^{85} ACTIVITY VALUES

Post-Injection Period (*Hours*)	Dose Contained in 2.5 Liters of Serum Following Intravenous Injection of Sr^{85} (*Per cent*)				
	Subject 1	Subject 2*	Subject 3	Subject 4	Subject 5
1/20	17.0		24.4	23.9	
1/12		2.16			17.8
1/6	14.8	3.08	17.4	15.4	17.8
1/4	14.1		15.4	13.9	16.0
1/3		5.25			
1/2	11.8	8.00	11.1	10.0	12.5
1	10.6	9.90	9.55	8.75	12.8
2	8.55	10.3		6.97	9.50
4	7.35	7.80	5.47	6.30	7.75
6	6.28	6.85	5.18	4.70	6.75
8					6.50
11			4.38	3.20	
12	4.97				
13		5.50			
22		4.12		2.47	
24	3.32		2.85		3.90
30			2.30	2.01	
31					3.60
36	2.60				
48	1.70	2.35	1.59	1.44	2.60
72	1.29		1.10	0.943	1.85
84	0.940	1.51			
96	0.645		0.856	0.708	1.40
120	0.492	1.13	0.675	0.505	1.23
144		0.80	0.56	0.50	0.88
168		0.76	0.478	0.39	
192		0.58		0.36	

* Subject 2 received a perivenous injection.

cleared from the serum by the kidneys, expressed in liters of serum cleared per twenty-four hours was calculated by dividing the cumulative urinary excretion at the end of the experimental period by the integrated serum activity. It was found that the renal-clearance rate remained relatively constant during the experimental period since good agreement was obtained between clearance rates calculated for different intervals of twenty-four hours following administration of the isotope.

Because of the rapid fall in blood activity during the relatively long experimental periods studied, no allowance was made for individual variations in the lag in fecal output; the lag was routinely regarded as two days and the fecal output at Day t was considered to represent the intestinal excretion at Day t-2, t in this expression meaning the longest interval studied. The cumulative-intestinal and total-excretion curves could then be computed from the start of the experiment. Intestinal excretion was found to be about 20 per cent of the total excretion (a figure comparable to that previously reported [26]). Renal and intestinal excretory mechanisms cleared about twelve liters of serum of strontium per day (Table II). The total body retention at Day 5 (Table III), calculated from the excretion data, was about 45 per cent of the injected dose.

The activity determined by external counting over the thighs (Figs. 1-A, 1-B, and 1-C) rose to a peak value within a few minutes following injection of the isotope and then slowly declined to 25 per cent of the maximum value at twenty-four hours. In contrast to this, the knee count rose gradually to a maximum value in twelve to twenty-four hours

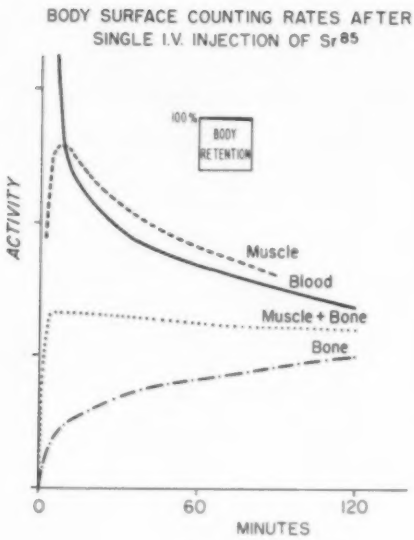

Fig. 1-A

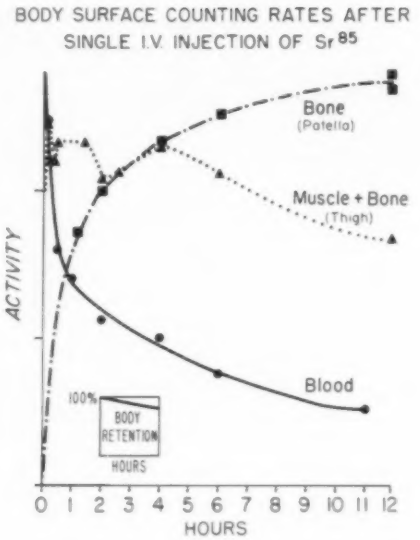

Fig. 1-B

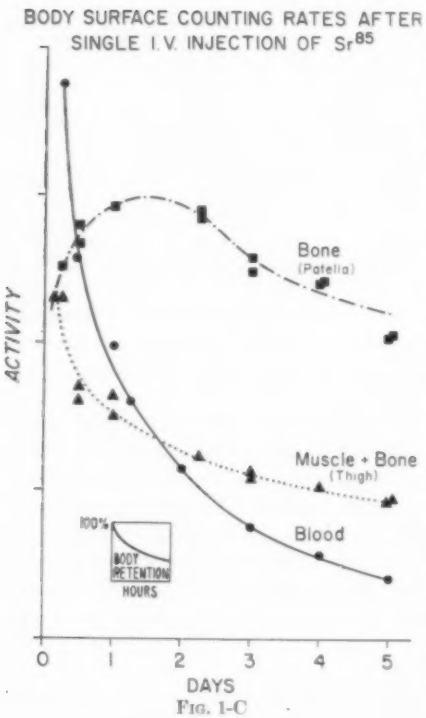

Fig. 1-C

Fig. 1-A: Graph shows plot of external counting rates continuously recorded over muscle (the adductors), muscle plus bone (the thigh), and bone (the patella). The curves for blood activity and body retention plotted against time after injection up to 120 minutes are drawn for comparison. The activity values are plotted against an arbitrary Cartesian scale. The relative magnitude of the external-counting rates are roughly correct, however. The subject on whom these recordings were made is not otherwise a part of this study.

Fig. 1-B: Same as Fig. 1-A, except that there were intermittent recordings up to twelve hours. These are recordings from Subject 4.

Fig. 1-C: Same as Figs. 1-A and 1-B except that intermittent recordings were made up to 120 hours. Recordings were made from Subject 4.

following injection. After twenty-four hours both the thigh and knee counts declined, the latter more slowly, and both more slowly than the serum activity.

Counts over the trunk (Fig. 2) indicated gross movement of the isotope among different parts of the body. In each survey plane 2.5 hours following injection of the isotope the counter detected roughly the same amount of activity regardless of its position. Thirteen days following injection, the counter gave considerably higher counts in positions over bone (for example, at 180 degrees, over the spinous processes) than over areas of predominantly soft tissues. (The high value of 315 degrees, Plane 4, may be due to isotope in the bowel one day after injection.)

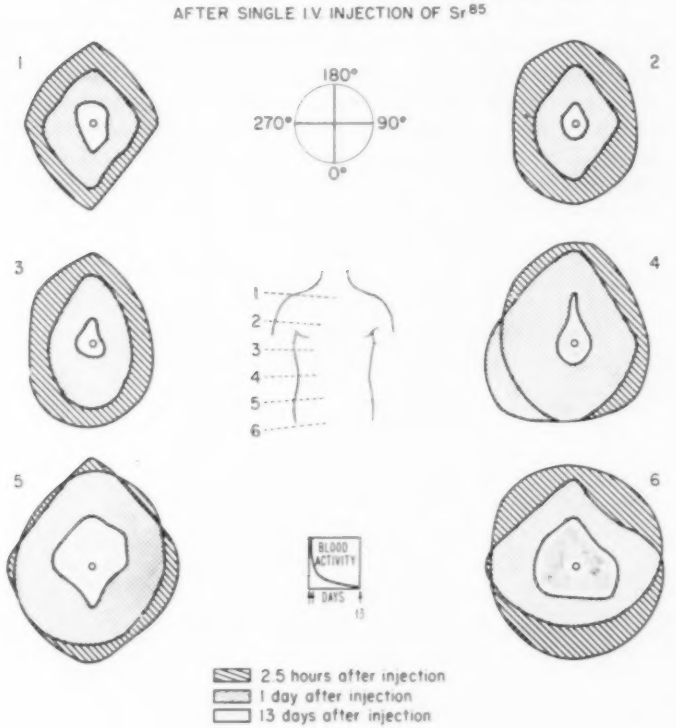

FIG. 2

Schematic drawing shows results of torso survey of Subject 3. The activity recorded at each of the forty-eight positions at each of the three intervals after injection is plotted from the centers.

DISCUSSION

Mathematical Analysis of Data

Results of tracer studies in which isotopes of calcium [5, 8], phosphorus [2], strontium [2], and barium [6, 9] were used, suggest that from a kinetic standpoint strontium is present in

TABLE II

SERUM-ACTIVITY COEFFICIENTS AND RATE CONSTANTS FOLLOWING INTRAVENOUS INJECTIONS OF Sr^{85}

Subject	A'_1	k'_1	A'_2	k'_2	A'_3	k'_3	A'_4	k'_4	u	a	E
1	0.888	0.346	0.036	0.0072	0.050	0.0010	0.025	0.00017	10	5.0	66
2	*	*	*	*	0.053	0.0011	0.036	0.00016	8.9	5.0	53
3	0.880	0.206	0.058	0.0072	0.042	0.0011	0.023	0.00017	14	5.6	82
4	0.900	0.278	0.034	0.0052	0.042	0.0014	0.024	0.00022	19	5.1	79
5	0.880	0.479	0.084	0.0193	0.052	0.00097	0.036	0.00017	8.3	3.6	57
Mean	0.870	0.326	0.0531	0.00972	0.0478	0.00113	0.0288	0.000176	12.0	4.86	67.4

* Not calculated (perivenous injection)
$k' = 0.693/T_{\frac{1}{2}}$ when $T_{\frac{1}{2}}$ is expressed in minutes
u = Excretory-clearance rate (liters of serum cleared from strontium per twenty-four hours)
a = Accretion-clearance rate (liters of serum cleared from strontium per twenty-four hours)
E = Strontium space (apparent volume of distribution expressed as liters of serum)

the body in two essentially different fractions: a comparatively small fraction which is exchangeable, and a second, a major fraction of the skeletal strontium, which is not. Radioactive strontium introduced in the blood stream mixes with the entire exchangeable strontium (that is, the strontium space; compare with sodium space) and is incorporated into the non-exchangeable strontium fraction by accretion (formation) of new bone.

Once incorporated into the non-exchangeable part of the bone salt, the labeled strontium is unavailable for exchange with the strontium of the strontium space in the same sense as radioactive iron incorporated into erythrocytes during synthesis of hemo-

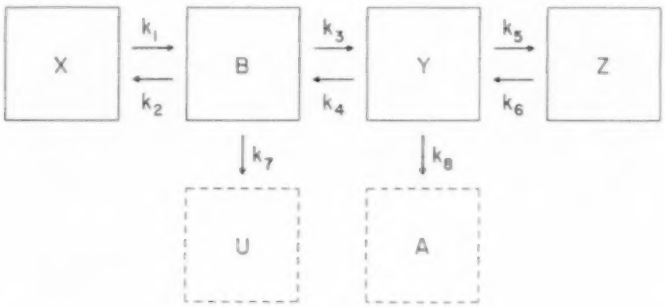

FIG. 3-A

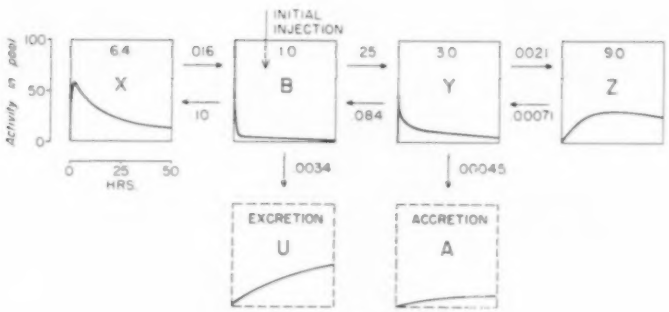

FIG. 3-B

Fig. 3-A: Drawing of postulated model for strontium metabolism. Compartment B represents the vascular space (serum). The nature of compartments X, Y, and Z is unknown. Excretion and accretion proceed at rates k_7 and k_8, respectively. The boxes U and A, containing activity drained from the system by excretion and accretion, have been outlined with dots to symbolize that they do not represent true compartments; uniform mixing is not presumed to occur in, for instance, the accretion box.

Fig. 3-B: Schematic drawing of the observed serum and excretory activity (B^* and U^*) simulated with an electronic analogue computer. The figures within the boxes indicate relative volumes derived from the k values, the volume of B being the unit of reference. (The rate constants k_1—k_8 are expressed in terms of decimal fractions per minute.) For comparison, the activity-time curves for the first fifty hours following administration of activity into B are schematically indicated (see Figs. 4-A and 4-B.)

globin is unavailable for equilibration with circulating plasma iron during the life span of the erythrocytes.

Kinetically the exchangeable strontium space can be divided into two or more compartments [4]. When labeled strontium is introduced into one of these compartments, it mixes within the strontium space by way of reversible processes (exchange) and is lost from the strontium space by accretion and excretion. When equilibration has been attained, the multi-compartment system can be described as one compartment, provided

sampling of any one of the compartments represents the behavior of the entire system (the validity of this statement will be discussed later).

If the *minimum* life span (not to be confused with *average* life span) of the bone salt is longer than the length of time required for equilibration of labeled strontium within the strontium space, E, an exponential decrease in the strontium-space activity, E^*, will be observed once equilibration has been attained (since $dE^*/dt = -k'E^*$ where k' is the fractional-removal rate). Plotted against time, the logarithm of the activity (and of the specific activity) of the strontium space will therefore appear as a straight line. The half-life, $T_{\frac{1}{2}}$, of this exponential will give the fractional-removal rate from the system, E:

$$k' = 0.693/T_{\frac{1}{2}} \tag{1}$$

If accretion and excretion remove a and u units per time unit, respectively, of stable material at specific activity S_B from the serum compartment, B, of the exchangeable space, E, and one unit of activity were administered at $t=0$, then (at any interval until labeled material starts to return to the strontium space from the non-exchangeable fraction):

$$1 = E^* + (a + u)\int_0^t S_B dt \tag{2}$$

At activity equilibrium

$$S_E = S_B \tag{3}$$

and since

$$E^* = E \times S_E \tag{4}$$

and

$$k' \times E = a + u \tag{5}$$

substitution in equation (2), division of all terms by E and inversion gives

$$E = \frac{1}{S_B + k'\int_0^t S_B dt} \tag{6}$$

Equation (6) can be solved for E by experimental determination of S_B. Equation (5) can be solved for $(a + u)$. As u can be experimentally determined ($u\int_0^t S_B dt$ = excretion), a can now be obtained. (The most convenient way to determine $\int_0^t S_B dt$ and u is to make semilogarithmic plots of S_B and the twenty-four-hour excretion values. The final exponentials of both these sets of data should be parallel after the equilibration period. If S_B is plotted in terms of fraction of dose per liter of serum and excretion in fraction of dose per twenty-four hours, the ratio of the amplitudes of these exponentials will be u, expressed as liters of serum per twenty-four hours.)

Using the data of the present study, the E, a and u values were calculated according to the method described in this report, the principle of which has been published elsewhere [5]. Since the concentration of stable strontium in the serum was too small to be determined conveniently, the value for E is given in terms of relative volume of distribution, one liter of serum being the unit of reference. Similarly, accretion and excretion are expressed as clearance rates, that is, liters of serum cleared of strontium per time unit (twenty-four hours). The mean values (E = 67.4 liters, a = 4.86 liters per twenty-four hours, and u = 12.0 liters per twenty-four hours) and the values for each subject are given in Table III. The clinical significance of these parameters will be discussed elsewhere.

Analysis of Data by Analogue Computer

In the preceding mathematical analysis it was assumed that some of the various compartments of the strontium space were in rapid exchange with the serum and that the tracer became uniformly distributed in a volume of fluid having the same concentration

of strontium as the serum. The average value, E, obtained by making these assumptions was 67.4 liters — a value considerably in excess of the total body water. The assumptions are obviously false, and the value for E represents, at best, the *apparent* volume of distribution. To determine whether part of the activity at equilibrium is contained in a solid phase, or whether, at equilibrium, one or more of the compartments constituting the total pool, E, has a higher specific activity than the serum, or both of these possibilities, would require knowledge of the kinetics of the entire exchangeable space. Theoretically this information could be obtained by serially sampling the different compartments, but from a practical standpoint this is not feasible. To solve this problem, a kinetic model was constructed (Fig. 3-A) and the behavior of the model analyzed with an electronic analogue computer.

The theory of the analogue computer has been described in detail elsewhere [12]. Briefly, the computer is an electric network of capacitors and resistors, with appropriate devices for recording voltages. The network is so constructed that the flow of charge from capacitor to capacitor simulates (hence, analogue) the transfer of labeled ions (here Sr^{85}) from compartment to compartment. The various capacitances are made proportional to the strontium space in the corresponding compartments, and the resistances between compartments are chosen to control the rates of transfer of electric charge. At zero time, a unit charge is put into the capacitor representing the blood compartment, just as a unit quantity of Sr^{85} is introduced into the blood in the human subject. As the electric charge travels from capacitor to capacitor, the transient voltages produced are proportional to the specific activities of the corresponding compartments. When capacitances and resistances are adjusted to correspond to data obtained by observations on the subject, the computer affords a rapid analysis of movements of ions and of their time constants. This information could otherwise be obtained only by greatly increasing the numbers and complexity of observations on each compartment under study.

The finding that the serum-activity curve (B*) could be described as a sum of four exponentials (Table II) suggests that the strontium space consists of at least four different compartments. This four-compartment system is drained by excretion and by accretion. If serum is one of these compartments it seems reasonable to drain excretion from the serum compartment, B. As bone salt probably is not precipitated directly from the serum, it seems reasonable to drain by accretion from a compartment other than serum, but in rapid exchange with serum. One will then arrive at a model similar to that illustrated in Figure 3-A.

The following quantitative data are known about the model:

1. The size of compartment B representing serum (the figure used in this study was 2.5 liters, an estimate of the serum volume of an adult man).
2. B*, the total activity of the serum.
3. U*, the activity lost through fecal and urinary excretion.
4. k_7 (because $k_7 = U^* / \int_0^t B^* dt$).

The following equations characterize the system:

$$dX/dt = -k_1X + k_2B \quad (7)$$

$$dB/dt = -(k_2 + k_3 + k_7)B + k_1X + k_4Y \quad (8)$$

$$dY/dt = -(k_4 + k_5 + k_8)Y + k_3B + k_6Z \quad (9)$$

$$dZ/dt = -k_6Z + k_5Y \quad (10)$$

$$dU/dt = k_7B \quad (11)$$

$$dA/dt = k_8Y \quad (12)$$

The values of the parameters k_1 through k_8 are sought since they define not only the rates but also the relative sizes of the compartments X, B, Y, Z.

The computer used for analysis of the data herein reported was the REC model

TABLE III

BODY RETENTION OF Sr^{85}

Subject	Dose Retained Following Intravenous Injection of Sr^{85} (*Per cent*)				
	Day 1	Day 2	Day 3	Day 4	Day 5
1	74	63	56	51	47
2*	78	68	60	55	51
3	74	63	54	49	44
4	67	54	45	38	34
5	79	67	59	54	49
Mean	74	63	55	49	45

* Subject 2 received a perivenous injection.

C-302 d-c analogue computer used by Huff and Judd in studies of iron metabolism. Turnover-rate constants were represented by potentiometer settings, the compartments of the model by amplifiers, and the activities in the compartments by voltages over the amplifiers. The amplifier corresponding to compartment B (blood) was initially loaded with 100 volts, and the voltage over this amplifier was directly proportional to B*. This signal was recorded on a Speedomax recorder (maximal deflection corresponded to 100 volts). A switch permitted the recorded voltage to be multiplied by factors of ten and 100 in order to increase the accuracy of the reading. The voltages over the other amplifiers (corresponding to X*, Y*, Z*, U*, and A*) were recorded in the same way. The stability of the instrument during each run was kept better than 3 per cent. In translating machine time into biological time, two different settings were used: one second of machine time corresponded to four minutes of biological time, and one second of machine time corresponded to forty minutes of biological time. The paper of the recorder moved at a speed of two inches per minute. One inch on paper therefore corresponded to two and to twenty hours of biological time. A zero-to-maximal deflection of the recording pen took one second (corresponding to two and to twenty minutes of biological time).

Data for simulation on the computer were obtained as follows: The four exponentials of the serum-activity curves (Table II) were averaged term by term, and the resulting curve for B* up to 120 hours following injection of the isotope was computed. (Subject 2 was injected subcutaneously and only the last two exponentials of his serum activity were used, covering the interval from ten to 120 hours following injection.) The average excretion curve, U*, was obtained by averaging the individual excretion values day by day (from twenty-four hours to 120 hours following injection) as shown in Table III. The values for B* and U* were plotted on the paper of the recorder, and the potentiometers of the computer were then set to simulate the plotted values for B* and U* (essentially a trial-and-error procedure). The rate factors k_1 to k_8 for the model were deduced from the potentiometer settings. The *relative sizes* of the compartments X, Y, and Z (relative to compartment B) were calculated by introducing the k values in equations (7) to (10) and equating the left-hand members to 0. The *absolute sizes* of the compartments were then calculated on the basis of 2.5 liters for compartment B. The turnover rates and the relative sizes of the compartments are given in Figure 3-B.

The *absolute* amounts of *activity*, X*, Y*, Z*, and A* were obtained by recording the voltages over the amplifiers (Figs. 4-A and 4-B). The *specific activities* of compartments X, Y, and Z were obtained by dividing X*, Y*, and Z* by the respective volumes (using the volume of compartment B as the unit of volume). These values are given in Figure 5. For purposes of comparison the *specific-activity ratios* of X, Y, and Z to B are shown in Figures 6-A and 6-B.

It may be seen from the graphs that compartment Y exchanges so rapidly with B that peak activity is reached within minutes following injection of the isotope into B,

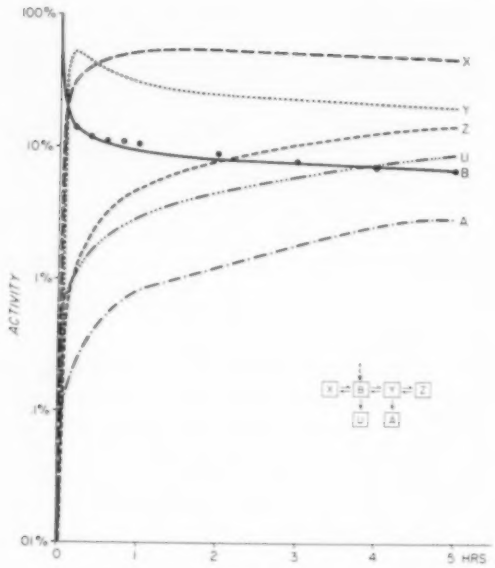

FIG. 4-A

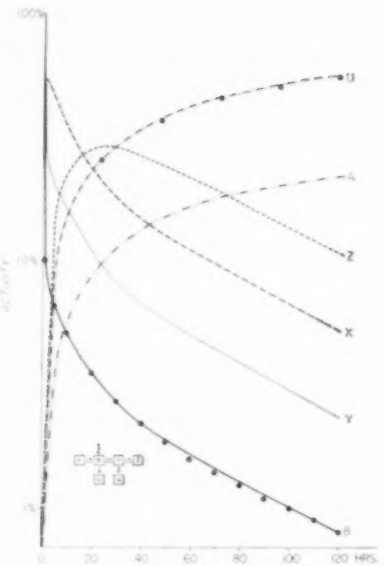

FIG. 4-B

Figs. 4-A and 4-B: Graphs showing computer-derived values for X*, B*, Y*, Z*, U*, and A*. Observed values for B* and U* are indicated with dotted lines.

Fig. 5: Graph shows specific activities of X, B, Y, and Z expressed in terms of amount of activity per volume of B.

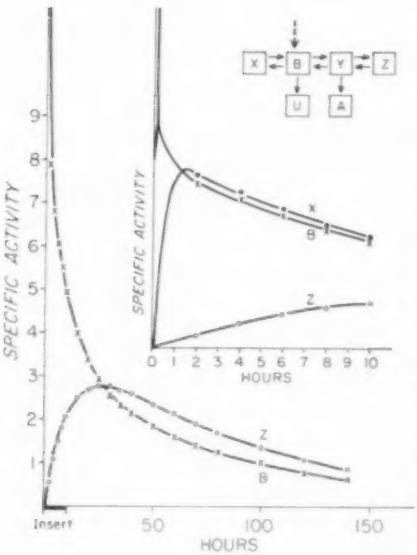

FIG. 5

The specific activity in Y from then on is practically the same as that in B. Peak activity of labeled material in X is reached between one and two hours following injection, and then parallels (has a constant ratio to) B but is 1 to 2 per cent higher (this was such a constant finding that it probably does not represent inaccuracy in the computer). Compartment Z does not reach peak activity until twenty-four hours following injection of the isotope, and equilibrium between B, Y, and Z is not reached until about seventy hours following injection. The specific activity in Z is then 1.4 times higher than that in B. This means that the *apparent volume* of distribution of strontium (calculated by sampling from B) in X + B + Y + Z was about 20 per cent higher than the *actual volume* of the exchangeable strontium space (the absolute volume of Z being about half of that of the absolute volume of X + B + Y + Z, as shown in Figure 3-B). This discrepancy between apparent and actual volumes of the strontium space will increase with increasing rates of excretion and accretion (k_7 and k_8).

If one attempts to define the compartments in terms of anatomical entities, one must remember that instantaneous mixing is obtained in a model compartment whereas some time is required for even intravascular mixing to occur in the body. However, this need

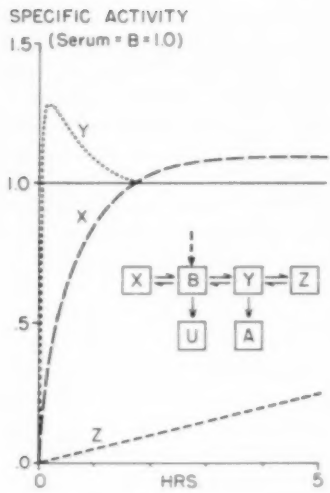

FIG. 6-A

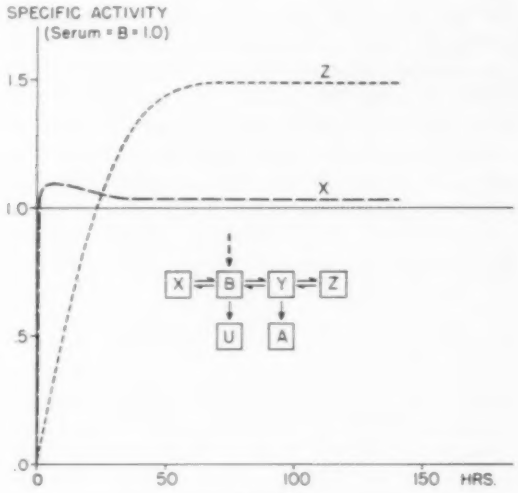

FIG. 6-B

Figs. 6-A and 6-B: Graphs showing specific-activity ratios of X, Y, and Z over B (S_X/S_B, S_Y/S_B, S_Z/S_B).

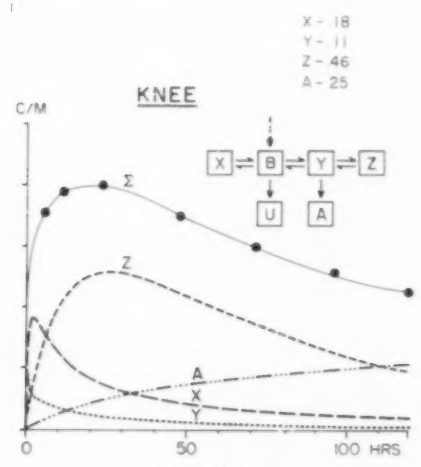

FIG. 7-A

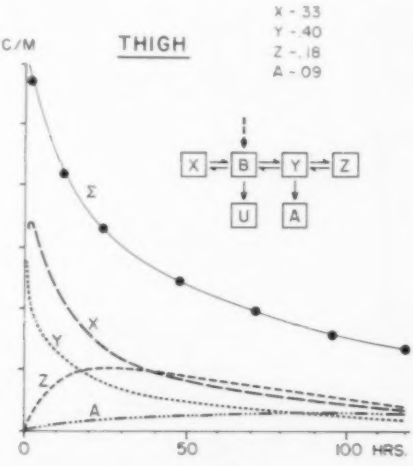

FIG. 7-B

Fig. 7-A: The knee activity, determined by external counting, is plotted against an arbitrary Cartesian scale. Decimal fractions (recorded in the right upper corner of the graph) of the computer-generated X*, Y*, Z*, and A* were chosen so that the sum simulates the observed knee-count curve. (If the knee activity had been representative of the entire body, all these decimal fractions would have had values equal to 0.25. B* has been omitted in the calculations because its contribution to the total body activity is unimportant after the first brief interval following injection in B of the isotope; at least it is unimportant as compared with the error involved in this type of calculation.)

Fig. 7-B: Graph representing the computer simulation of the thigh count. Note the predominance of accretion and exchangeable-bone curves (A and Z) in the knee simulation, and in contrast, the predominance of the supposedly extraskeletal curves (X and Y) in the thigh simulation.

not invalidate interpretation of compartments in anatomical, or rather, physiological, terms since the compartments of the model may be regarded as statistically valid analogues of different families of biological compartments, each family having its own kinetic character. If one assumes that the concentration of stable strontium in compartments X, Y, and Z was 70 per cent of that in serum [17, 21] one arrives at volumes for compartment

X of 22.8 liters, for Y of 10.7 liters, and for Z of 32.1 liters. Compartment B plus Y total 13.2 liters, and X plus B plus Y total 36.0 liters. In reviewing body composition, Moore and associates give 16.4 liters as the value for extracellular water and 39.8 liters for the total body water (in a normal man weighing seventy kilograms). It is tempting to assume, therefore, that compartment Y represents the extravascular, extracellular space and compartment X the intracellular space. No body-water phase fits with Z; it is too large, and judging from deuterium-oxide studies of water metabolism in humans [3], it exchanges too slowly to represent more than a fraction of the body fluids. Hence compartment Z probably represents a solid phase, that is, the skeleton, since it is the only important storehouse for strontium in the body.

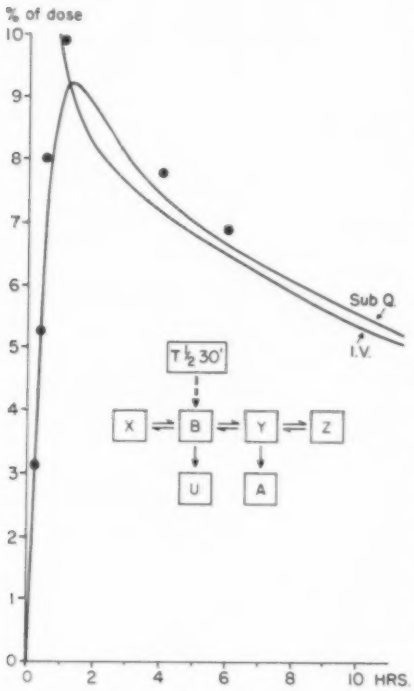

FIG. 8

Graph showing results in Subject 2 who was injected perivenously. The activity left the injection site with a $T_{\frac{1}{2}}$ of thirty minutes. The observed B* values in the patient are plotted together with the previous computer-derived B* curve (I.V.), and the new B* curve (Sub Q) derived from a model in which all k values were the same as previously but with a new compartment from which the "isotope dose" was drained into B with a $T_{\frac{1}{2}}$ of thirty minutes.

To further test the foregoing assumptions, external counting was carried out as a substitute for actual serial sampling of body structures. Comparison of the activity curves obtained from recordings over muscle, muscle plus bone, and bone (Figs. 1-A, 1-B, and 1-C) with activity curves generated by the analogue computer (Figs. 3-B, 4-A, and 4-B) immediately reveals rough agreement between muscle and compartments X and Y on one hand, and between bone and compartment Z on the other.

The analogue computer was, however, also used for a detailed analysis of the curves obtained from external counting. The curve for the counting rate recorded over the patella (combined data from Subjects 1, 3, 4, and 5) was simulated on the computer by summing fractions of X*, Y*, Z*, and A*. (B* was omitted because Y* is representative of B* a few minutes following injection.) The fractions of the various compartments were determined by potentiometer settings. Recordings made over the thigh (muscle and bone) were analyzed in the same way. The results are shown in Figure 7-B. The counter located over bone detected proportionally more of compartments Z and A than of the other compartments. On the other hand, the counter over the thigh detected proportionally more of compartments B, X, and Y. Thus, analysis of the data obtained from external counting lends support to the assumption that the activity curves of the model compartments X and Y represent processes outside the bone salt, and that the activity curves of Z and A picture bone-salt processes.

An example of the application of computer analysis to a special problen is the case of Subject 2, in whom the isotope was injected perivenously. Surface-counting revealed that the isotope disappeared from the injection site at a $T_{\frac{1}{2}}$ of approximately thirty minutes. For computer simulation an extra compartment was added to the system. "Activity" was drained from this extra compartment into the B compartment with a potentiometer setting equivalent to a $T_{\frac{1}{2}}$ of thirty minutes. The potentiometer settings

representing all other values for k's of the system were left unchanged. The values for the serum activity obtained with the computer were compared with the observed values (Fig. 8). The observed values and the computer-generated values showed good agreement.

It is customary in isotope investigations to assume that the subjects are in a steady state with respect to the element investigated. This assumption is often false for one or both of two reasons: (a) the rate of ingestion of, for instance, strontium, iodine, or iron usually varies with the time of day; and (b) the subject studied may be in the process of developing a new steady state [12], such as in anaemia or osteoporosis. The error involved in (a) can be offset by extending the study over a sufficiently long period. The error in (b) can be partly offset by making the period studied short enough. In practice these possible

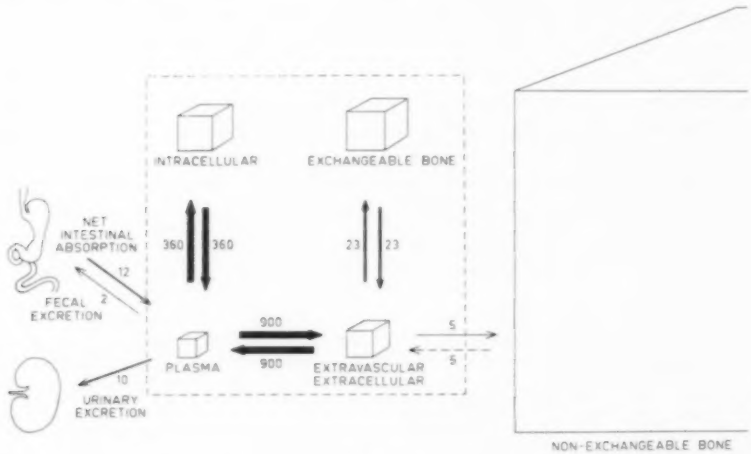

FIG. 9

Drawing of a tentative model of the kinetics of strontium metabolism in man. This model is based on the values presented in Fig. 3-B. The relative compartment sizes are indicated by the sizes of the cubes, the unit amount of strontium being that present in one liter of serum. The rate values are expressed in unit amount of strontium per twenty-four hours. "Plasma" contains 2.5 units of strontium. The construction of the model presented in Fig. 9 has been done in the following way. The amount of strontium going from "Plasma" to "Intracellular" will be 2.5 (i.e., "Plasma" strontium content) times 0.10 (i.e., fractional-removal rate per minute, see Fig. 3-B) times 60×24 (i.e., to express the rates in terms of twenty-four hours instead of minutes) = 360.

The large cube designating non-exchangeable bone is not a true compartment but a store of strontium. Release of strontium from this store is *not* a random process. The strontium space (in the sense used in this article) comprises four exchangeable compartments as indicated in the drawing. It should be emphasized that the authors do *not* believe this model to be a true representation of the kinetics of strontium in the body. The postulated model is one of many which will simulate observed *in vivo* activity data. Minor alterations in the model (for example, insertion of a shunt between the extra vascular-extracellular and intracellular compartments) does not change the order of magnitude of the processes outlined. Studies of alternative models are in progress.

errors probably do not often introduce difficulties in interpretation of the data. In the present study, the assumption that the subjects were in zero strontium balance and that their strontium spaces were not expanding or contracting during the investigation seems reasonable. Thus the rate of *net* absorption of strontium from the food to the blood was the same as the rate of *net* excretion of strontium from the body. The term *net* is introduced because some strontium excreted into the intestine is resorbed, and a major fraction of the strontium filtered through the glomeruli is resorbed in the renal tubules. (It is conceivable that such processes might be hidden in one or more of the "exchange compartments".) One would then arrive at a model for the kinetics of strontium in the body as outlined in Figure 9.

If one tries to translate this model into a model for calcium metabolism, certain difficulties are encountered. Although the volume of the exchangeable space and the rates of accretion and resorption are similar to those for calcium [5], the following differences between the two elements should be pointed out: (a) excretory-clearance mechanisms are more efficient for strontium than for calcium (by a factor of about four) [2, 24, 26]; (b) the "final" exponential for strontium is not reached until three days following administration, while Krane and associates found that the blood activity started to fall exponentially 1.5 days following Ca^{45} administration; (c) the concentration of strontium in intracellular fluid may be about the same as that in extracellular, in contrast to the concentration of calcium which is higher in extracellular than intracellular water (unless compartment X consists principally of exchangeable bone, it may not be comparable to any compartment for calcium). Work is in progress to further elucidate the differences and similarities between calcium and strontium metabolism. It is hoped that this will aid in obtaining data related to the model for the mechanism postulated by McLean by means of which exchange of calcium between blood and bone maintains homeostasis. It is also hoped that future studies of cases where the parameters of the model deviate from normal (for example, as in Vitamin D-deficiency rickets [7], fracture cases [1], hypothyroidism, hypoparathyroidism, Paget's disease [17], and idiopathic osteoporosis [24]) will help to test the validity of the model adopted in the current study. The feasibility of such an analysis is suggested by the finding that five days following administration of the isotope to Subject 1, the fractured heel gave a ten-times higher counting rate than did the normal heel. Two months later this ratio was six to one.

NOTE: Explanation of symbols and units used in text and tables: The symbols, units and definitions adopted in this paper correspond whenever possible with those used by Huff and Judd, and particularly by Brownell [25].

The rate constants are defined as the fractional loss of stable material per time unit from the compartment in question. Unless stated otherwise, the unit of volume is the liter even for compartments which might partly or entirely consist of solid material. This is amplified in the text and in the legend for Fig. 9. Unit amount of strontium is thus the amount of strontium contained in one liter of serum. Units of activity are expressed in terms of percentage of total dose.

Symbol	Unit	Definition
E†	None, and unit amount of stable material	Total strontium space (Sum of B, X, Y, Z)
B	None, and unit amount of stable material	Intravascular strontium compartment
X, Y, Z	None, and unit amount of stable material	Extravascular strontium compartments
a	Unit amount/unit time	Accretion clearance rate, amount of stable material removed per time unit from E by transfer to the non-exchangeable fraction of the body strontium
u	Unit amount/unit time	Excretory-clearance rate, amount of stable material removed per time unit from E by excretion
E*, B*, X*, Y*, Z*	Per cent	Per cent of dose in E, B, X, Y, and Z, respectively (at t time units following administration of isotope)
A*, U*	Per cent	Per cent of dose removed from E by accretion and excretion, respectively (at t time units following administration of isotope)
k_1 to k_3	Fraction/unit time	Rate constants for processes pictured in Fig. 3-A
S_E, S_B, S_X, S_Y, S_Z	Percentage of dose per unit amount of stable material	Specific activities of compartments E, B, X, Y, and Z, respectively
A'_1 to A'_4	Fraction of dose	Amplitudes of exponentials derived from B*
k'_1 to k'_4	Fraction/unit time	Rate constants of exponentials derived from B*
t	Minutes or days	Time following administration of isotope

† When used in equations these capital letters indicate amounts of stable material contained in the compartment, that is, the compartment sizes.

SUMMARY AND CONCLUSIONS

Strontium metabolism was studied in five adult males by external counts over various body locations, and serial samples of serum, urine, and stools for seven to fourteen days

following parenteral administration of radioactive strontium (Sr^{85}, physical half-life, sixty-five days), were collected.

With the use of a d-c analogue computer, it was possible to simulate the blood-disappearance and excretory-appearance curves with a four-compartment model and two bleed-outs, one representing loss of isotope from the exchangeable strontium space due to new-bone formation (accretion) and one representing excretion.

The rates involved in this model suggested that the four compartments represent serum, extravascular-extracellular fluid, intracellular fluid, and bone strontium. The latter represents about half the total exchangeable strontium space.

The model is presented as a possible point of departure for further investigations of the many unknowns which remain to be defined for a true representation of the kinetics of strontium, calcium, or other bone-mineral metabolism.

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Radiation Sterilization of Homogenous-Bone Transplants Utilizing Radioactive Cobalt

PRELIMINARY REPORT *

BY PAUL H. DEVRIES, M.D., CARL E. BADGLEY, M.D., AND J. TED HARTMAN, M.D.,
ANN ARBOR, MICHIGAN

Since December 1954, radioactive cobalt has been used at University Hospital to sterilize bone[2], blood vessels[10], and cartilage[9] transplants. This paper is a preliminary report of the experimental and clinical results with irradiated bone-bank bone.

Radiation sterilization of bone-bank bone was investigated because our use of frozen bone and boiled or autoclaved bone had resulted in too high an incidence of postoperative wound infections and unsatisfactory results.

Orthopaedic procedures upon children and patients who are poor surgical risks demand that adequate supplies of sterile bone be available at all times. In maintaining supplies of sterile bone, two principles must be considered. The tissue must be sterile and it must be preserved by a method that will not grossly alter its structural integrity or physiological state. To accomplish this, the tissue must either be obtained under sterile conditions and kept sterile during its processing, or the tissue must be sterilized by one means or another after it has been obtained and processed.

To assure sterility, bone transplants have been boiled[3] or soaked in various types of antiseptic solutions[15,16]. To assure adequate preservation of the tissue, it has been subjected to freezing[18] and freeze-drying[7]. These methods, however, have their disadvantages. Obtaining sterile bone at the time of the autopsy and freeze-drying it has been shown to be an excellent method of maintaining a bone-bank[7], but the technical difficulties involved in obtaining sterile bone are numerous and the method does not always assure the surgeon that the tissue obtained is sterile. It should be pointed out that freeze-drying does not sterilize tissue, and, in fact, has proved an excellent method of preserving many types of bacterial and viral organisms.

Prior to the use of radiation sterilization at University Hospital, all homogenous-bone transplants were autoclaved before their use in the operating room. Autoclaving, however, results in the denaturation of the osseous protein. This denaturation has been described as an internal rearrangement of the peptide chains which thereby changes the basic physical properties of the protein, and is considered a factor retarding revascularization of the transplant[7]. Gallie[3,4] and Reynolds and associates concluded that boiled bone, although capable of carrying out the functions of fresh or frozen bone, does so more slowly than autogenous bone. Odell, Mueller and Key pointed out that autogenous bone is best suited for a free graft. Autogenous bone, superior primarily because of its specificity, causes less reaction by the host. Therefore, there is more rapid revascularization and replacement. Gallie noted that the rapidity of union of boiled bone to living bone, and the rate at which it is absorbed and replaced, depend largely on the density of the bone used. This observation undoubtedly led to the increased use of cancellous bone for transplant procedures. Os purum, described by Orell, is bone that has been freed of fat, connective tissues, and proteins by means of a lengthy extraction process. This effort to produce a transplant that can be readily revascularized was recently renewed by Losee and Hurley, who reported the use of ethylenediamine in extracting most of the organic constituents from bone.

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, February 2, 1956.

FIG. 1-A

FIG. 1-B

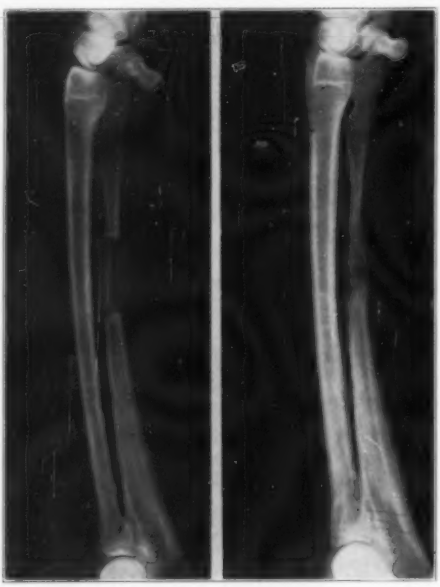

FIG. 1-C

Figs. 1-A through 1-C: Roentgenograms made of irradiated transplants in the mid-ulnar shaft of dogs.

Fig 1-A: Roentgenograms made ten days and four months postoperatively. Note union proximally and non-union distally.

Fig. 1-B: Roentgenograms showing appearance of transplants two weeks and nine weeks postoperatively.

Fig. 1-C: Note union distally and non-union proximally as shown in roentgenograms made one week and ten weeks postoperatively.

The bone-bank problem, therefore, is one of how best to provide sterile tissue that is readily revascularized, absorbed, and replaced by the host with a minimum of reaction by the host. Any process of sterilization or preservation that denatures the protein constituents of bone would probably retard the process of revascularization and absorption.

It is known that high-intensity gamma radiations from radioactive cobalt will inactivate certain bacteria and viruses, and that it is useful in the preservation of meat and other food products. It has also been found that certain enzymes are only slightly altered by relatively large doses of gamma radiation [12]. Parenteral fluids have been sterilized by gamma radiation and administered to animals without harmful effects [5]. Experimental studies conducted in dogs [2] and mice [6] have demonstrated that the gamma radiation from radioactive cobalt will completely sterilize bone contaminated with bacterial and viral organisms. It was our hope that the use of radiation sterilization utilizing radioactive cobalt would provide a sterile transplant readily acceptable by the host.

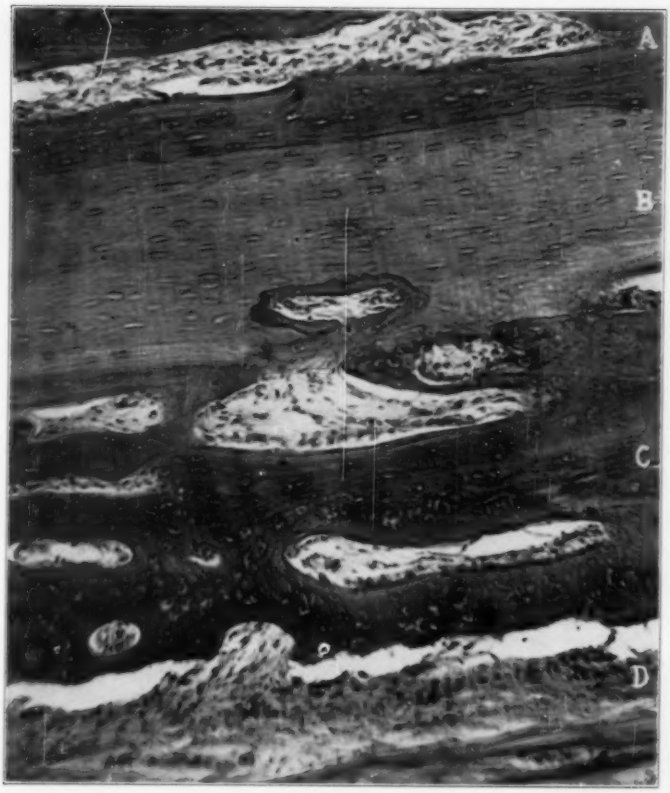

FIG. 2

Photomicrograph of bone removed from ulna pictured in Fig. 1-C ten weeks following transplant. Approximately two-thirds of the irradiated transplant has been replaced with living bone (*A* and *C*, new bone; *B*, dead transplant; *D*, periosteum).

FIG. 3

Ilium removed at autopsy is cut into thin strips on a band saw.

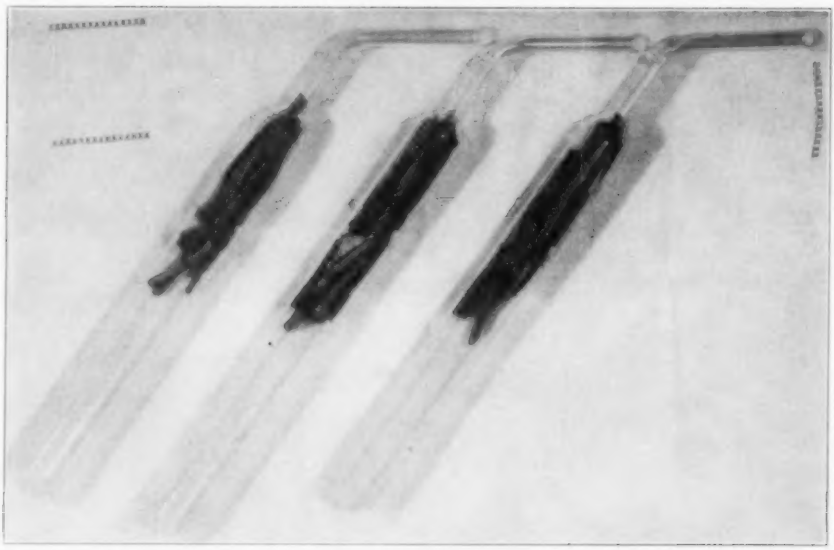

FIG. 4

Strips of ilium are shown after being placed in pyrex tubes, the ends of which will be sealed with a gas-oxygen torch.

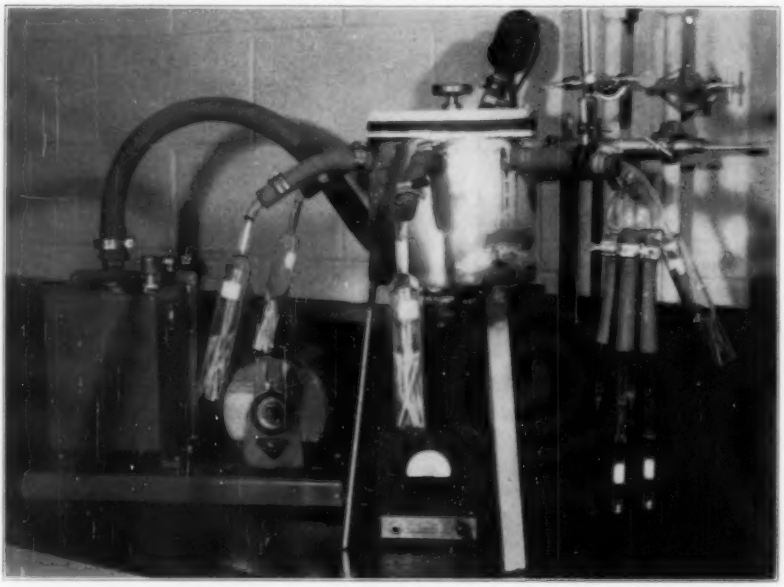

FIG. 5

Four tubes containing human bone can be seen fastened to the vacuum apparatus. The vapor pressure gauge is below the manifold, the vacuum pump is at the left. At the right are smaller samples of dog bone; two small tubes have been removed.

Most bacterial organisms, except various gram-positive rods, are destroyed by one million roentgen equivalent physicals. When the level of radiation is increased to two million roentgen equivalent physicals, all bacterial organisms are destroyed. Bactericidal

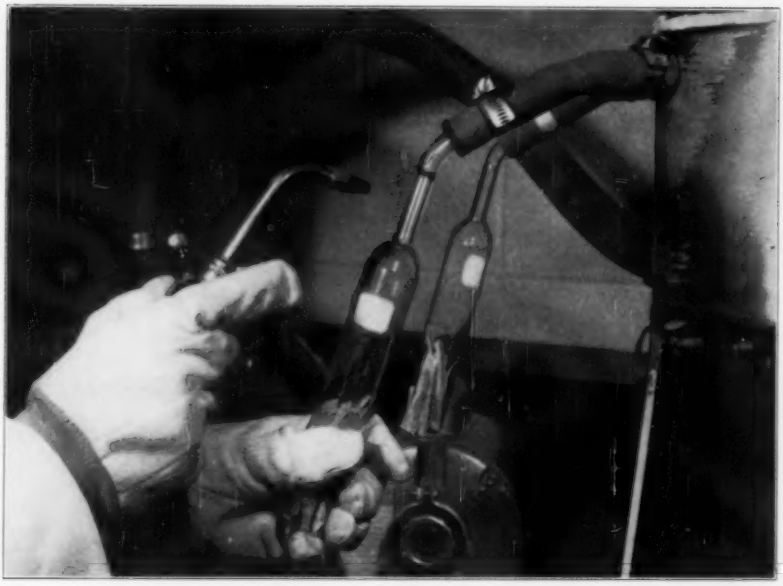

FIG. 6

At the end of the freeze-drying process, the tubes are cut off while the pump is running.

FIG. 7

Two sealed pyrex tubes containing freeze-dried strips of ilium. The lower tube, which is dark, has been subjected to four million roentgen equivalent physicals. The color change may be a result of oxidation of ferrous chloride to ferric chloride, in the glass.

radiation levels in dogs were determined by exposing pieces of rib contaminated with pure cultures of *Clostridium botulinum* and *Clostridium tetani* to various levels of gamma radiation [2]. Spore-forming organisms were used since they have been shown to be more resistant to radiation than the common vegetal organisms and fungal contaminants. Other experimental procedures carried out by the authors, in which bone obtained at autopsy and known to be contaminated with a wide variety of gram-positive and gram-negative rods was used, further substantiated that two million roentgen equivalent physicals is a minimum bactericidal radiation level.

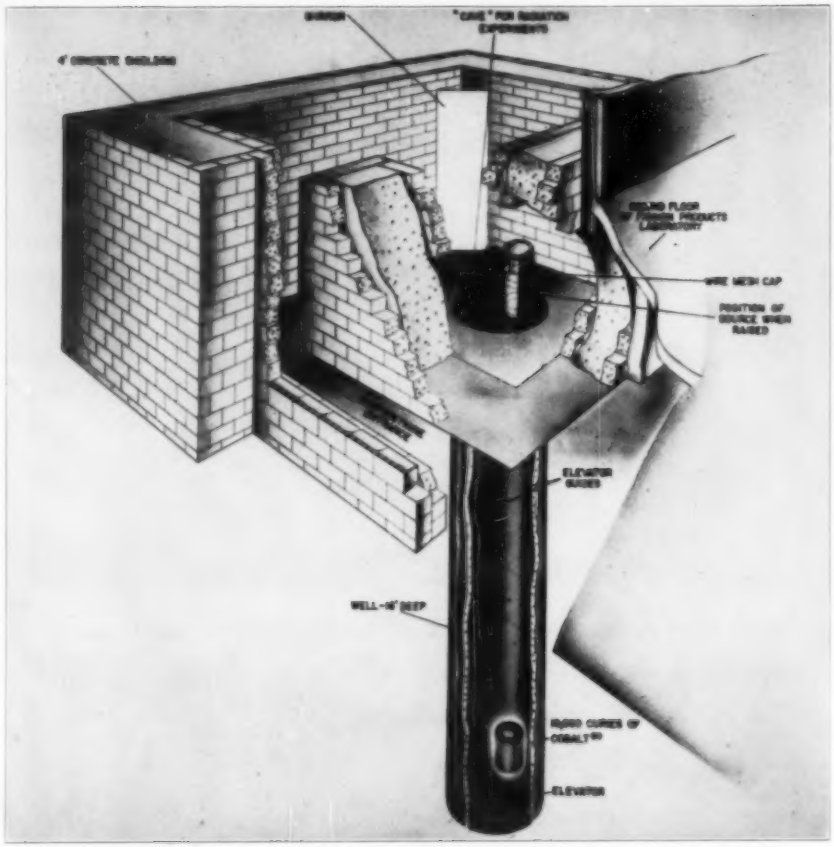

FIG. 8

Schematic drawing of radioactive cobalt source.

Virucidal radiation levels were determined by performing transplants in rats with rat tibiae known to contain living vaccinia, poliomyelitis, or Novy viruses [5]. Other experiments have demonstrated that smaller viruses, such as the poliomyelitis virus, require four million roentgen equivalent physicals for complete inactivation [6]. It is of interest to note that the Novy virus is the most resistant known virus to the usual virucidal agents and is the virus re-isolated after a culture tube had lain dormant and dry for over twenty years.

Experiments conducted by the authors in dogs and rats demonstrated that irradiated bone when transplanted produced no immediate harmful effects and functioned well in stimulating new-bone formation in fracture sites. Figures 1-A through 1-C represent the roentgenographic appearance of irradiated transplants used to fill gap fractures in the mid-ulnar shaft of dogs. Figure 2 is a photomicrograph of a representative dog transplant showing its partial replacement with living bone. The failure of complete bone union demonstrated in Figures 1-A and 1-C occurred in approximately one-third of the experimental animals. Lack of adequate immobilization was felt to be the main factor contributing to non-union.

Other experimental and clinical investigations utilizing cathode-ray sterilized transplants by Meeker and Gross, Cohen, and Turner and associates also demonstrated that

FIG. 9

Photomicrograph showing irradiated homogenous cancellous bone one month following radiation sterilization. This human iliac bone was stored at + 15 degrees centigrade for three days prior to freeze-drying and irradiation.

tissue transplants can be sterilized with ionizing radiation and subsequently function satisfactorily. Our own experimental procedures and the reported experimental procedures of others investigating radiation sterilization of tissue transplants justified a clinical trial of homogenous-bone transplants sterilized with radioactive cobalt. A standardized method of processing and sterilizing bone-bank bone was therefore initiated.

METHOD OF PROCESSING

Both iliac crests are removed from bodies known to be free of infectious and neoplastic diseases. The bone is stripped of all soft tissue and cut into the desired shapes and sizes on a heavy-duty band saw (Fig. 3). The bone is then washed in ordinary tap water to remove accumulated dirt and débris. This vigorous washing under running water removes much of the marrow from the thin strips of ilium. Some of the iliac strips are cut into smaller pieces in a bone mill. After cleaning, cutting, and washing, the bone is placed in pyrex tubes (Fig. 4), and the large open ends of the tubes are sealed. The tubes are then immersed in a mixture of dry ice and alcohol for approximately twenty minutes after which they are affixed to the vacuum apparatus (Fig. 5). It was found that approximately fourteen days are required to remove most of the water from the bone, but if there is an immediate need for the transplant, the process can be terminated twenty-four to forty-eight hours following initiation of the drying process. To remove the tubes from the apparatus, a gas-oxygen torch is used to seal the small end while the pump is running (Fig. 6). The tubes of bone are then taken to the radiation source and subjected to a sterilization dose of four million roentgen equivalent physicals. The tubes can be stored at room temperature. Figure 7 represents the appearance of the freeze-dried bone before and after radiation sterilization.

The radiation source used consists of 100 aluminum-jacketed cobalt rods stored in a

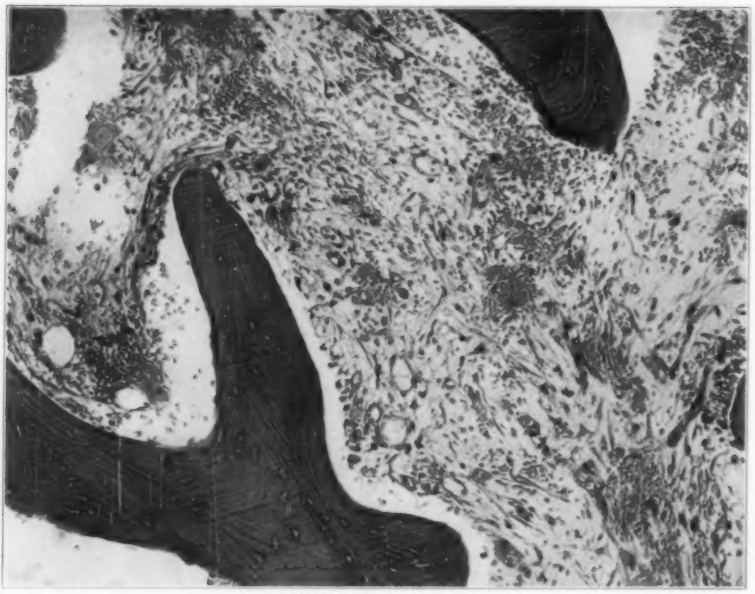

FIG. 10

Photomicrograph of the bone made two weeks following transplantation. The necrotic marrow has been replaced with a vascular type of connective tissue.

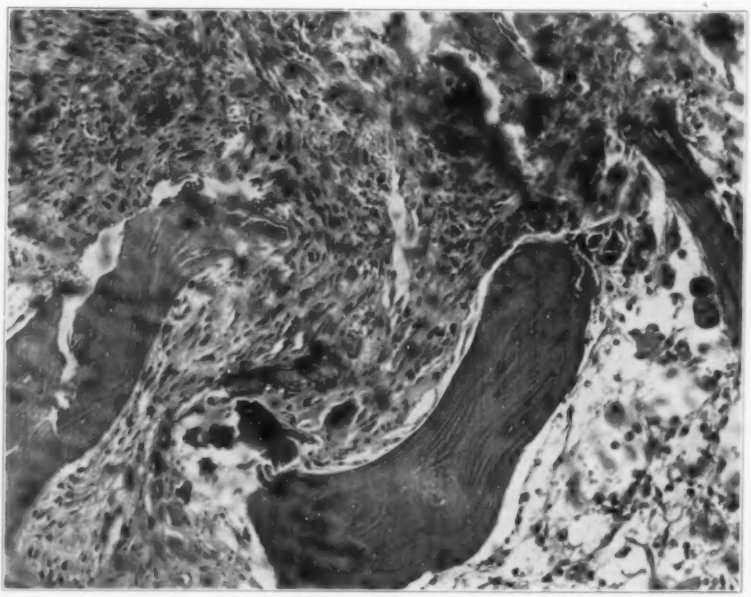

FIG. 11

Bone removed from another patient two weeks following transplantation is shown in photomicrograph. This demonstrates a somewhat different type of host reaction from that shown in Fig. 10.

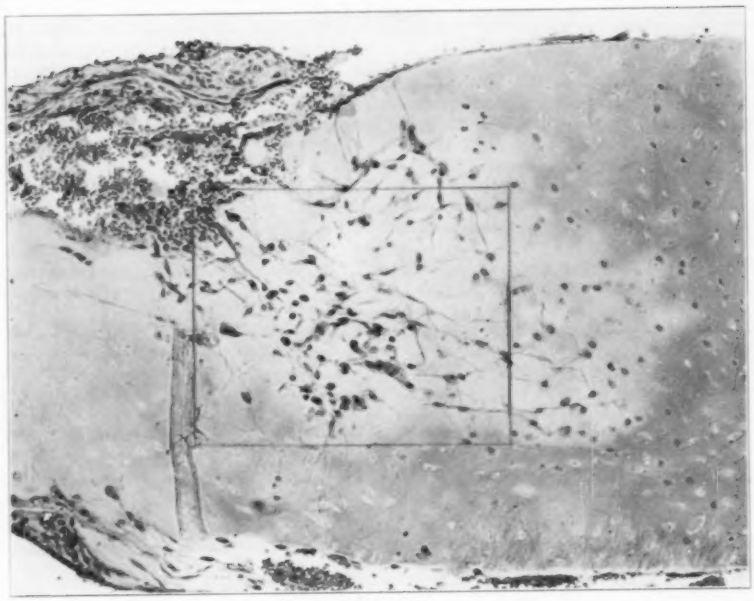

FIG. 12

Fibroblastic invasion of irradiated cartilaginous tissue after transplantation with apparent transformation of fibroblasts into immature cartilaginous type cells is shown in photomicrograph.

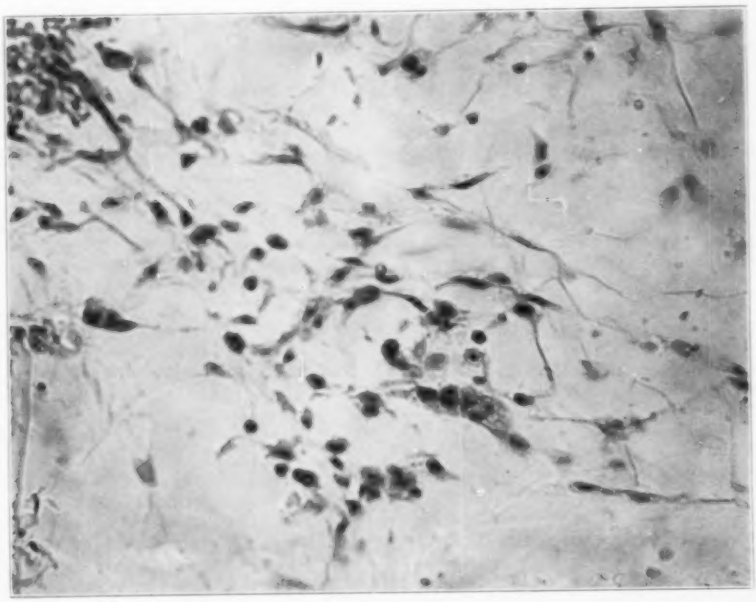

FIG. 13

Photomicrograph of portion outlined in Fig. 12.

TABLE I

Hospital Case No. and Diagnosis	Age (*Years*) Sex	Operation	Culture	Organism Cultured from Bank-Bone
D. S., No. 732667 Paralytic rotational scoliosis	8 M	Spine fusion, T5 to T12, 2–7–55; spine fusion, T11 to S2, 2–18–55	Negative	None
D. J., No. 752671 Recurrent unicameral bone cyst	12 M	Obliteration of cyst with inlay-onlay grafts, 2–13–55	Positive	*Bacillus subtilis*
J. D., No. 802826 Idiopathic rotational scoliosis	14 F	Spine fusion, T4 to L1, 2–22–55	Positive	Coagulase-negative *Staphylococcus albus*
M. L., No. 731842 Paralytic rotational scoliosis	12 F	Spine fusion, T10 to S2, 4–2–55	Negative	None
W. F., No. 717854 Paralytic scoliosis	6 M	Spine fusion, T4 to L2, 8–12–55	Positive	Non-hemolytic coagulase-negative *Staphylococcus albus*
S. H., No. 823263 Idiopathic scoliosis	12 F	Spine fusion, T5 to T11, 10–20–55	Positive	Diphtheroids
H. S., No. 621606 Delayed union of femoral-neck fracture; infected	44 F	Osteotomy and reinforcing bone graft, 11–21–55	Negative	None
F. H., No. 830362 Bone cyst of proximal phalanx right thumb	5 M	Curettement and inlay-onlay bone graft, 1–19–56	Positive	Diphtheroids
J. P., No. 829297 Paralytic rotational scoliosis	12 F	Spine fusion, T4 to T11, 2–28–56; spine fusion, T10 to L2, 3–13–56	Negative	None
D. B., No. 831222 Traumatic arthritis of right wrist	31 M	Arthrodesis of right wrist, 4–23–56	Positive	Hemolytic coagulase-positive *Staphylococcus albus*
A. B., No. 819342 Tuberculous osteomyelitis of the spine	69 M	Spine fusion, T11 to L3, 5–7–56	Positive	Coagulase-negative *Staphylococcus aureus*
M. L., No. 844889 Sacralization of L5 and postoperative spine fusion with pseudarthrosis at L5 and S1	17 F	Re-fusion of L5 to S1 7–10–56	Negative	None
A. Y., No. 850013 Paralytic rotational scoliosis	15 M	Spine fusion, T2 to T8, 11–14–56; spine fusion, T8 to L2, 12–10–56	Negative Negative	None None

TABLE I

Wound Repair	Late Results
Wound partially separated on the fifth postoperative day with 2 areas of profuse seropurulent drainage in the lumbar area. This slowly responded to antibiotics. Coagulase-positive *Staphylococcus aureus* was cultured from the drainage.	Twelve months postoperatively there was an obvious pseudarthrosis at L2 and L3, and L4 and L5 which corresponded to the site of persistent postoperative drainage.
Wound healed by primary intention in ten days.	No evidence of recurrence or infection ten months postoperatively.
Wound healed by primary intention.	Solid bone fusion obtained and maintained when patient last seen 20 months postoperatively.
Lumbar wound separated down to the deep fascia and drained purulent material following removal of sutures. Mild drainage for 21 days postoperatively, eventually healed. Organisms cultured from the wound: *Pseudomonas aeruginosa* and hemolytic coagulase-positive *Staphylococcus aureus*.	Pseudarthrosis developed at L3 and L4, and L5 and S1 requiring re-fusion 17 months postoperatively. Following the second attempt at fusion, the wound again broke down and drained and the same organisms were cultured as previously for 3 months. Wound closed at 4 months with no roentgenographic or clinical evidence of fusion.
Wound healed by primary intention in 10 days with no evidence of infection.	Solid fusion clinically and roentgenographically 10 months postoperatively.
Wound healed by primary intention in 10 days; second procedure performed T11 to L4, 11-1-55.	Definite failure of fusion 11 months postoperatively, at T10 and T11. No evidence of chronic infection
Minimal seropurulent drainage appeared on the fourth postoperative day which disappeared on the tenth postoperative day following treatment with antibiotics.	Painful non-union developed necessitating Colonna arthroplasty. There was clinical and microscopic evidence of chronic infection present at the time of the arthroplasty and drainage persisted 3 months postoperatively.
Wound healed by primary intention in 7 days with no evidence of infection.	Definite recurrence of bone cyst with complete absorption of transplant apparent 6 months postoperatively.
Both first-stage and second-stage wounds partially separated 4 days following the second-stage procedure. Non-hemolytic coagulase-positive *Staphylococcus aureus* was cultured from the drainage. Both wounds slowly healed with the exception of 2 small draining sinuses in the lowermost portion of the second-stage wound.	Two small, draining sinuses still present 1 year postoperatively in the lowermost portion of the lumbar wound. Fusion solid clinically and roentgenographically 1 year postoperatively.
Wound healed by primary intention in 10 days with no evidence of infection.	Solid fusion obtained 5 months postoperatively.
Soft-tissue wound infection obvious on the fifth postoperative day necessitating removal of sutures. On the seventh postoperative day portions of the transplanted bone were removed. Profuse purulent drainage persisted for 6 weeks. Coagulase-positive *Staphylococcus aureus* isolated from the purulent drainage.	Most of transplant either extruded or absorbed at 7 months with failure of fusion and 2 persistent, draining sinuses.
Slight serosanguinous drainage evident on the tenth postoperative day which subsided on the seventeenth postoperative day.	Solid fusion obtained with no evidence of chronic infection 6 months postoperatively.
At the first-stage procedure, the skin was burned with a Bouie coagulation apparatus, and mild seropurulent drainage was present for 2 weeks postoperatively. The second-stage procedure was performed 4 weeks following the first-stage procedure; this wound broke down upon removal of the sutures and 4 areas of drainage were established. The wound separation extended down to the deep fascia and coagulase-positive *Staphylococcus aureus* was cultured from the drainage.	Six months postoperatively there was one small area of superficial granulation tissue. There was roentgenographic evidence of incorporation of the bone graft with no evidence of chronic osteomyelitis on pseudarthrosis.

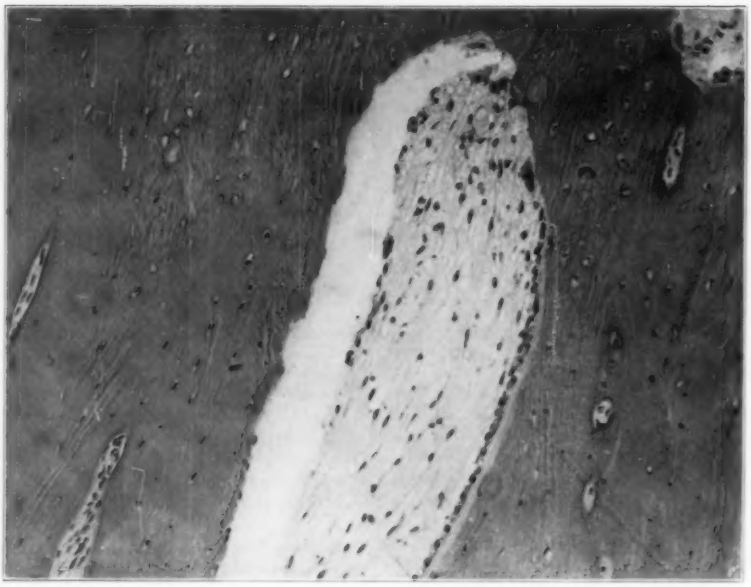

FIG. 14

Photomicrograph made one year following transplantation of bone shown in Figs. 9 and 10, at transplant site. Complete replacement of the graft with living bone has occurred.

water well within a concrete cave (Fig. 8). The concrete cave is large enough to allow large quantities of material to be irradiated. The material to be irradiated is first placed in the cave. Then the radiation source is raised from the water well up into the radiation chamber by means of a remote-control winch. After a proper amount of time has elapsed, the source is lowered into the water well and the irradiated material can be removed from the radiation cave with safety. This method produces sterile bone that is easily stored and transported. The tubes of bone retain no residual radioactivity. Depending upon the size of the radioactive source, a dose of four million roentgen equivalent physicals can be administered in from six to twenty-four hours. Electron accelerators can administer four million roentgen equivalent physicals in a matter of seconds but have the disadvantage of low penetrability, thereby preventing sterilization of large pieces of bone sealed in glass or metal containers. The ionizing radiation from radioactive cobalt, on the other hand, has high penetrability, thereby eliminating this undesirable feature.

Photomicrographs of irradiated bone transplants before and after transplanting are shown in Figures 9 through 14. In Figure 9 there can be seen a portion of human iliac bone and its marrow. Prior to being processed and sterilized, this bone was stored at +15 degrees centigrade for three days. It was then freeze-dried and subjected to four million roentgen equivalent physicals. A normal cellular pattern of marrow is absent and no cells are present in the lacunar spaces. The postmortem autolysis, occurring during the three-day storage period, probably accounts for this change and can be prevented, for the most part, by quick-freezing the bone after its removal from the body.

Portions of this homogenous-bone transplant were used in the first stage of a two-stage spine fusion procedure upon a twelve-year-old girl with idiopathic rotational scoliosis. Two weeks following the initial procedure, the wound had healed well and the second stage was undertaken. At this time a portion of the previously transplanted bone was removed and examined microscopically. The microscopic appearance of this trans-

FIG. 15-A

FIG. 15-B

FIG. 15-C

FIG. 15-D

Figs. 15-A and 15-B: Case 1. Roentgenograms made four months after tibial fracture. There is little evidence of callus formation.

Figs. 15-C and 15-D: Roentgenograms made five months after reinforcing bone transplant procedure show early evidence of bone union.

Figs. 15-E and 15-F: Roentgenograms made seven months postoperatively show solid bone union.

FIG. 15-E

FIG. 15-F

planted bone is pictured in Figure 10. The necrotic marrow has been absorbed and replaced by a vascular type of fibrous tissue. There does not appear to be any early absorption of bone trabeculae or evidence of new-bone formation. The early reaction of the host (Fig. 10) was observed to vary somewhat in different patients.

Figure 11 is a portion of a transplant removed from another patient two weeks following a first-stage spine fusion procedure. Here it can be seen that the reaction appears to be of a somewhat different nature; the marrow being replaced with a denser type of fibrous tissue. There are also present several multinuclear giant cells, possibly representing osteoclasts. There appears to be very early absorption of bone.

The early reaction of the host to irradiated cartilaginous tissue in these spine fusion procedures is of some interest. Figure 12 represents what was once a portion of the iliac apophysis transplanted with the bone shown in Figure 9. Although the cellular detail of adult cartilaginous tissue is recognizable, the nuclei do not stain uniformly and they appear necrotic. Along one edge there is apparent the ingrowth of young fibroblasts, some of which appear to be undergoing transformation to an immature cartilaginous type of cell. Figure 13 is a higher magnification of that area. Whether or not these young fibroblasts are undergoing transformation to an immature cartilaginous type of cell is debatable, but it does appear that the irradiated cartilage is being absorbed by the host and replaced with living tissue without evidence of foreign-body reaction. One year postoperatively, the bone transplant pictured in Figures 9 and 10 had been replaced with living bone (Fig. 14).

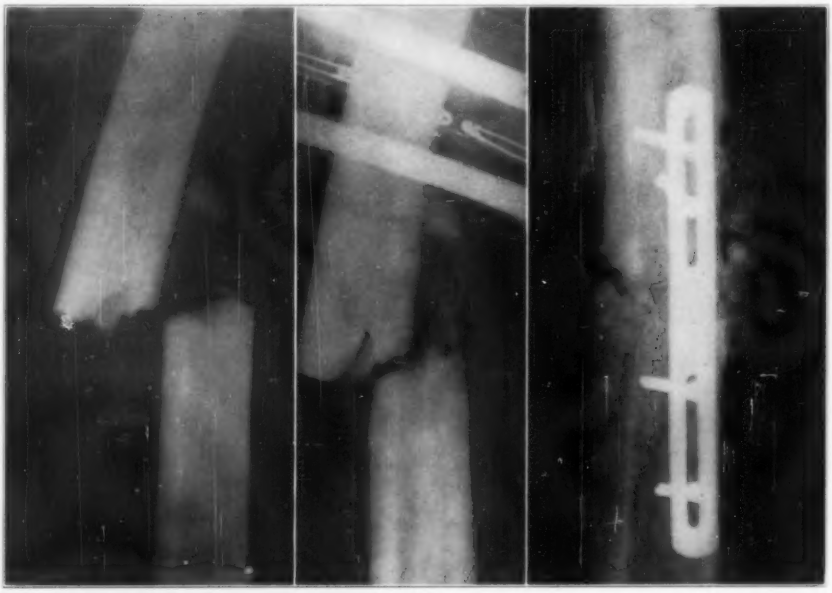

FIG. 16-A FIG. 16-B FIG. 16-C

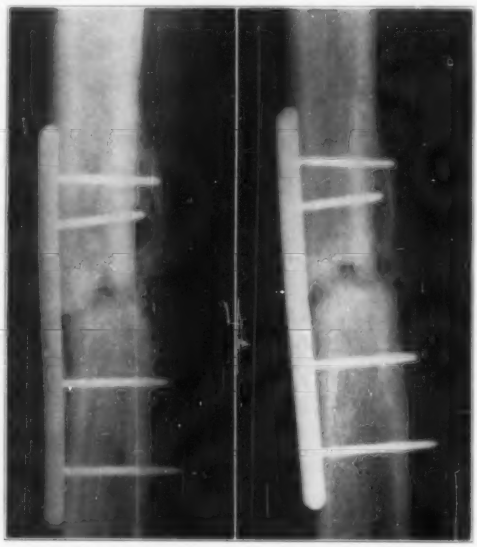

FIG. 16-D FIG. 16-E

Fig. 16-A: Case 2. Roentgenogram of right femoral shaft two weeks following closed fracture.

Fig. 16-B: Sixteen weeks following injury, roentgenogram shows that there is poor healing.

Fig. 16-C: Roentgenogram made two weeks following reinforcing homogenous-bone transplant procedure.

Fig. 16-D: Roentgenogram made three months postoperatively.

Fig. 16-E: Roentgenogram made six months postoperatively.

RESULTS OF OPERATIVE PROCEDURES UTILIZING IRRADIATED HOMOGENOUS-BONE TRANSPLANTS

This preliminary report is based on 104 operative procedures performed on eighty-two patients. In each instance, samples of the transplanted bone were cultured for bacterial organisms and the wound was closely observed postoperatively for signs of infection.

Seven positive bone cultures were obtained, all being of common throat and skin contaminants. Five wound infections occurred, the predominant organism in each case being a coagulase-positive *Staphylococcus aureus*. Four of the five wound infections were associated with a negative bone culture; only one wound infection was associated with a positive bone culture. The organism obtained from the bone culture in this case was a coagulase-negative *Staphylococcus aureus*. It should be pointed out that the *Staphylococcus aureus* organism is readily destroyed at levels of from one to two million roentgen equivalent physicals. We, therefore, believe that the five wound infections were from sources other than the irradi-

TABLE II

TYPE AND NUMBER OF OPERATIONS PERFORMED

Spine fusion	76
Repair of non-union of long-bone fracture	8
Repair of fresh fracture	7
Hip fusion	3
Excision of recurrent bone cyst	3
Wrist fusion	1
Shoulder fusion	1
Triple arthrodesis	1
Repair of pathological fracture	1
Correction of congenital pseudarthrosis	1
Excision of ossifying fibroma	1
Cranioplasty	1

ated transplants. Table I is a breakdown of these positive bone cultures and postoperative wound infections.

Irradiated homogenous-bone transplants were used mostly in spine fusion procedures upon children, but were also used in the treatment of bone cysts, delayed union and non-union of long-bone fractures, and as an added stimulant to fracture healing in fresh fractures of the forearm and humerus. Table II is a breakdown of the 104 operative procedures.

The following case histories are presented to demonstrate the efficacy of irradiated homogenous-bone transplants.

CASE 1. This Negro man, thirty-nine years old, had an open fracture of the distal portion of the tibia in October 1955. The initial treatment consisted in thorough débridement, primary closure, and immobilization in a toe-to-groin cast.

The wound healed by primary intention, and immobilization was maintained for four months, at which time it was felt that a reinforcing bone graft was indicated (Figs. 15-A and 15-B). This was carried out with irradiated homogenous bone. The surgical wound healed by primary intention and union slowly occurred. Nine months following the injury and five months postoperatively the patient was permitted partial weight-bearing (Figs. 15-C and 15-D). He walked freely eleven months after the injury and seven months postoperatively (Figs. 15-E and 15-F).

CASE 2. This white man, thirty-five years old, had a closed fracture of the right femoral shaft in February 1955 (Fig. 16-A). The fracture was initially treated by skeletal traction. Repeated attempts at manipulation and closed reduction were unsuccessful, and sixteen weeks following injury (Fig. 16-B), an open reduction was undertaken and a reinforcing homogenous-bone transplant was used in conjunction with a bone plate (Fig. 16-C). Three months postoperatively satisfactory progression of union had occurred, and the patient was able to walk in an ischial weight-bearing caliper (Fig. 16-D). Clinically and roentgenographically satisfactory union was felt to be present. Six months postoperatively the patient bore his full weight without support (Fig. 16-E).

CONCLUSIONS

Radioactive cobalt has been proved to be an effective means of sterilizing bone transplants. When combined with a freeze-drying process, radiation sterilization utilizing radioactive cobalt has proved an effective method of maintaining a bone-bank.

It has been found that irradiated bone transplants function satisfactorily both experimentally and clinically.

In 104 surgical procedures in which irradiated homogenous-bone transplants were used, five postoperative wound infections occurred. The irradiated bone transplants were not felt to be the source of these infections.

The encouraging over-all clinical results in 104 operative procedures prompt continued use of irradiated homogenous-bone transplants.

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DISCUSSION

Dr. Paul R. Lipscomb, Rochester, Minnesota: Five years ago, Hyatt, in closing the discussion of the paper he had presented on "The Preservation and Clinical Use of Freeze-Dried Bone," said that he and his colleagues had been investigating a technique for the treatment of bone with cathode rays in an effort to sterilize it without substantial damage to the proteins. Dr. DeVries and associates have proved that bone so treated can be absolutely sterilized. They are to be congratulated on their careful experimental studies and on their later clinical application of these studies.

Unfortunately, thus far the preparation of freeze-dried bone has not made the use of this substance practical for routine application in civilian practice. Furthermore, the added safety feature which has been described today will not be of immediate help to most of us.

Dr. Donald S. Childs, Jr., one of the radiotherapists at the Mayo Clinic, has commented on this paper as follows: "One of the things which immediately occurs to anybody reading the paper would be 'We have a cobalt ^{60} teletherapy unit. Can we use this unit to sterilize bone grafts and aortic grafts?' It should be pointed out that the unit at the University of Michigan is specifically designed for research in the sterilization of food and other products, and contains 10,000 curies. Our particular cobalt ^{60} unit, for example, contains 1,500 curies, and is one of the largest thus far produced for medical treatment purposes. I made some calculations to determine how long it would take to deliver the four million roentgen equivalent physicals which the authors say is necessary to inactivate the most resistant viruses. I think with our unit, at a reasonable distance away from the cobalt, 40 centimeters, we would need almost 415 hours of exposure. If we wished to utilize the unit when it is otherwise idle, over a week end, for example, we could successfully get four million roentgen equivalent physicals only by moving the target material to within 15 centimeters of the cobalt, but because of the system of shielding and collimation we would not be able to treat anything which occupies a space of more than five by five centimeters at this distance. I would guess that the use of the standard teletherapy units for this purpose is not practical."

Perhaps some day bone prepared as recommended by the authors will be available from one of the pharmaceutical houses, the larger universities, or, perhaps, through the Red Cross. Even if freeze-dried, radiation-sterilized bone does become available to each of us, we must remember that homogenous bone, regardless of its preparation or source, at this stage of our knowledge, is inferior to autogenous-bone transplants in exciting osteogenesis.

LIEUTENANT COMMANDER GEORGE HYATT, BETHESDA, MARYLAND: It is always a source of keen satisfaction to witness experimental efforts brought to the level of clinical application. That such a development exposes differences in working philosophy and methodology is only logical. As our working philosophy, we believe that the autogenous-bone graft is the superior graft. However, do the disadvantages of significantly increased operating time and blood loss, painful donor sites, pathological fractures, and increased morbidity offset the advantage of the superior bone graft? Many responsible orthopaedic surgeons indicate that they do not. Others, equally responsible, contend that the homogenous graft, while not the best, is adequate in selected cases.

The clinical research project at the Tissue Bank, National Naval Medical Center, Bethesda, Maryland, emphasizes tissue procurement and preservation. In the instance of bone, clinical evaluation is accomplished in association with Navy and civilian orthopaedic surgeons. Our records indicate that we have processed over 4,000 bone deposits obtained at approximately 100 sterile autopsies with an over-all contamination rate of approximately 8 per cent.

We agree with the authors' statement that freeze-drying is an excellent means of preservation. However, on theoretical grounds, storage at −50 degrees centigrade is as good and possibly better. We estimate that this is well below the temperature required to freeze the liquid salts in bone. Storage at such a temperature would be more realistic than the use of the relatively more elaborate freeze-dry apparatus, particularly if the stored grafts are mainly for local use. We in the Tissue Bank prefer to dry the bone from the frozen state because the process permits standardized production storage at room temperature and theoretically gives the bone an on-the-shelf life of over ten years.

(*Continued on page 231*)

A Brace for Correction of Torsion of the Lower Extremity

BY S. L. HAAS, M.D., SAN FRANCISCO, CALIFORNIA

Persistent torsion or rotation of the lower extremity may be corrected by the use of a suitable brace. It is necessary to have a constant force exerted on the limb to reverse the direction of the deformity.

A brace which has answered this requirement consists of a single bar extending from the upper portion of the thigh to the foot plate or shoe. The upper part is the fixed unit and is held in place by two well fitted, medium, soft leather lacers—one placed at the thigh and one just below the knee. These lacers are supplemented by malleable half-ring metal bands which conform to the shape of the limb (Fig. 1).

With an abnormally shaped limb, it may be necessary to place a layer of sponge

rubber or chamois skin on the under surface of the leather. It has not been necessary to use a pelvic band, but if slipping does occur in some patients, a pelvic band may be attached to the proximal element of the brace.

The lower or free-moving part of the brace consists of a rod which passes through a tube, this being welded onto the bar of the fixed upper unit. The constant rotation tension is obtained by a spring which is attached at one end of the upper fixed unit and at the other end to the lower, free-moving part of the brace.

A device for increasing the tension of the spring consists of a metal cylinder which can

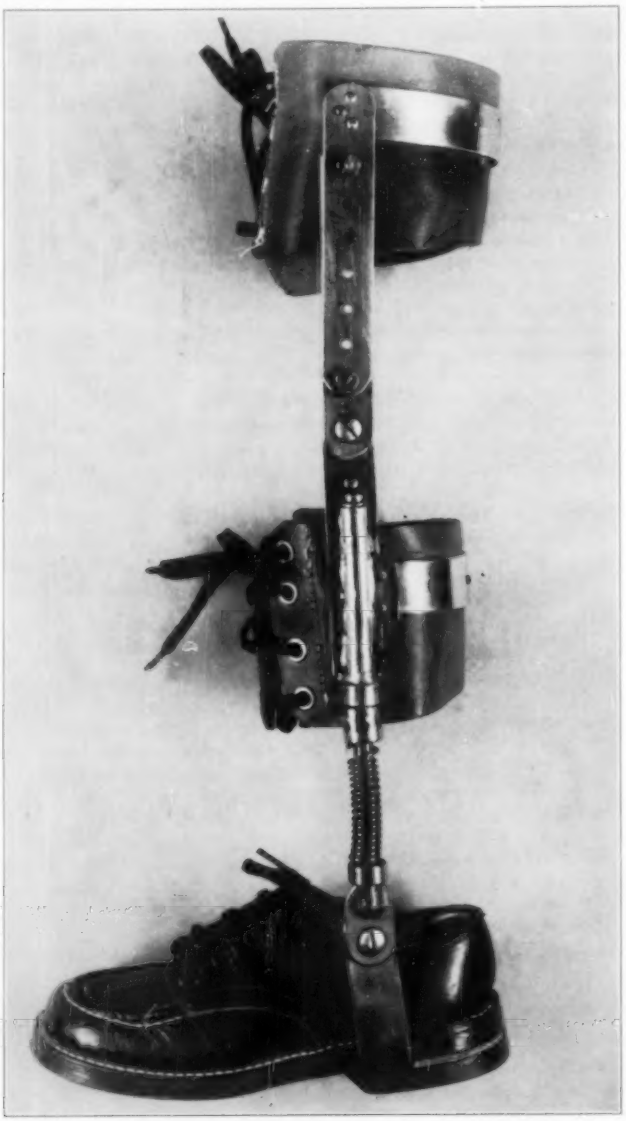

FIG. 1

The intact brace.

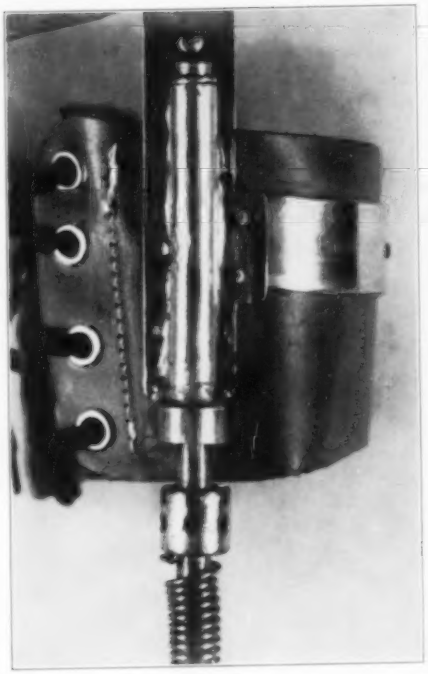

FIG. 2

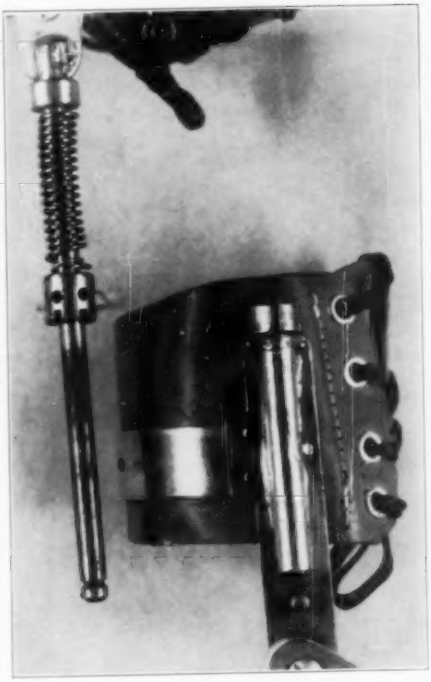

FIG. 3

Fig. 2: Showing the notched cylinder for increasing the tension of the spring.
Fig. 3: The lower unit of the brace detached by removing the countersunk split ring about the head.

be pulled away from the fixed portion of the brace by compressing the spring (Fig. 2). This cylinder can then be rotated in the desired direction to increase rotational force of the spring. The cylinder is notched on its upper rim and when replaced, fits into corresponding pegs on the fixed portion of the brace.

The entire lower unit may be detached by removing the countersunk, split ring just below the head of the rod at the upper end of the cylinder (Fig. 3). The small metal peg on the upper bar immediately above the head of the rod prevents the rod from migrating upward in the tube.

FIG. 4

Patient wearing brace for medial torsion.

The spring can be replaced by a right-wound or left-wound spring if a rotational force in the opposite direction is desired. When a longer rod and spring are necessary for a growing patient, they can be installed after detaching the lower unit. Lengthening of the upper part of the brace is made possible by perforated overlapping side bars above the knee.

Progressive Diaphyseal Dysplasia (Engelmann's Disease)

Report of a Case with Twenty-Two-Year Follow-Up

BY VICTOR G. MIKITY, M.D., AND GEORGE JACOBSON, M.D., LOS ANGELES, CALIFORNIA

From the Department of Radiology of the School of Medicine, University of Southern California, and the Los Angeles County Hospital, Los Angeles

Progressive diaphyseal dysplasia (a term suggested recently by Neuhauser and associates) was first described by Camurati in 1922, although its first report has commonly been attributed to Engelmann, whose account appeared seven years later. Characteristically, there is fusiform enlargement of the diaphyseal portion of any or all of the long bones produced by cortical thickening. The demarcation between the normal bone and the involved area is fairly abrupt and the epiphyses and metaphyses appear normal. Occasionally, thickening has been noted in the base of the skull.

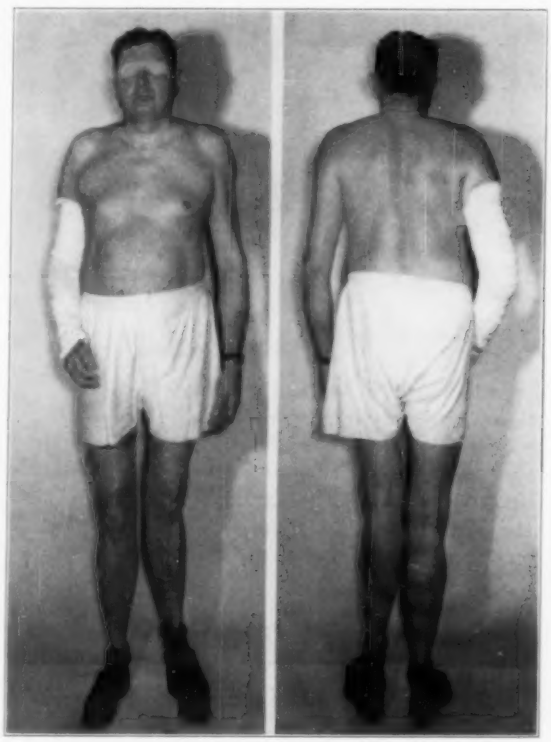

Fig. 1

The patient at the age of fifty-four shows good muscular development. His shortened left leg is due to an old fracture of the hip. His right arm is in a cast because of a recent fracture of the elbow.

Both sexes are involved with equal frequency, and with perhaps one exception, the patients in all of the reported cases have been Caucasian [5]. The diagnosis has been made in patients whose ages fell between thirty-three months and fifty-five years, the majority of patients being children. Most frequently, the disease is manifested by failure to walk at the normal age, followed by a disturbance in gait [1, 6, 8, 11, 14].

Bone biopsies were performed in at least eleven cases. The specimens showed that the thickening of the cortex is produced by endosteal and periosteal accretion of new bone. No abnormal cells have ever been described. The marrow is normal, although occasionally it may have a somewhat fibrotic appearance [11].

The etiology remains obscure. Most observers felt that the

Fig. 2-A: Roentgenogram made in 1934 showing both forearms. Symmetrical, somewhat irregular, cortical thickening has produced abruptly demarcated fusiform enlargement of the diaphyseal portions of the radii and ulnae.

Fig. 2-B: In 1955, slight progression has occurred in the distal ends of both radii and ulnae.

Fig. 3-A: 1935. Both legs. There is bilateral cortical thickening of the tibiae and fibulae which are less extensively involved than the bones of the forearm.

Fig. 3-B: Bones are unchanged in 1955.

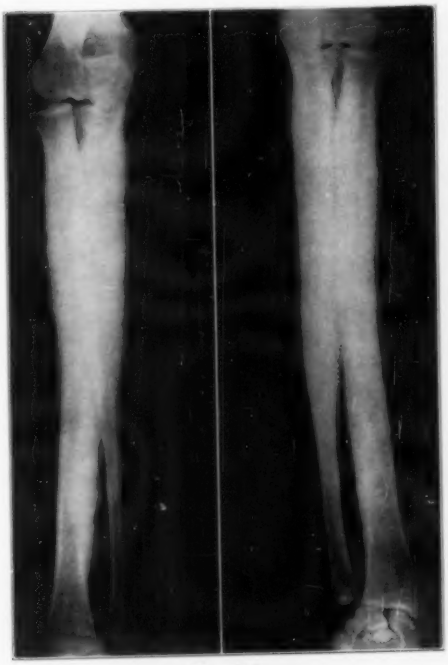

FIG. 2-A

FIG. 2-B

FIG. 3-A

FIG. 3-B

disease was limited to bone, but, as more cases have accumulated, many[4, 7, 8, 11, 15] have come to believe that the disease is probably systemic with the bone manifestations predominating. Reasons in support of this theory include the peculiar neurological findings[14] such as disturbances of motor function and the poor general nutritional status often evident. Griffiths suggested a genetic origin, citing "The early onset, the absence of abnormal

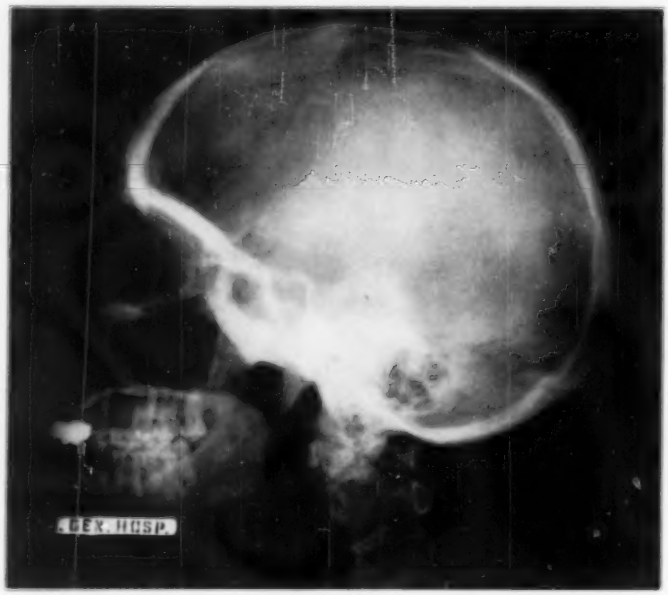

FIG. 4

Note the thickening of the bone at the base of the skull and of the inner table of the frontal bone.

cell-structure in such tissues as have been examined and the symmetrical progress in the skeleton . . ."

E. P. was first seen in the Los Angeles County General Hospital in 1934 at the age of twenty-nine years, complaining of intermittent aches and pains in all of his extremities. The attacks of pain, which he remembered from his fifth year, would last a few months, only to recur with equal severity. In 1933, the patient fell and fractured his left hip which was repaired in another hospital with a bone peg. The fracture healed with shortening of the limb and resulted in a painful hip. In 1934, an unsuccessful subtrochanteric osteotomy was performed, and the hip was fused surgically in 1954.

The patient reported that he had had the usual childhood diseases and had recovered from them without sequelae. He had had an appendectomy and tonsillectomy when he was ten years old.

The patient was a healthy, robust individual (Figs. 1-A and 1-B) able to earn a satisfactory livelihood. Results of repeated physical and neurological examinations were normal, with the exception of those findings associated with his fractures. He stated that his father, mother, and siblings were normal and, to the best of his knowledge, had had no bone disease. Within recent years the bone pain of which he had previously complained gradually disappeared.

Laboratory findings: The red blood count, white blood count, sedimentation rate, hematocrit and marrow were found to be normal. Levels of calcium, phosphorus, alkaline phosphatase, albumin, and globulin were within normal limits on repeated examinations. The serological findings were negative.

Roentgenographic examinations: Initially a skeletal survey showed fusiform cortical thickening limited to the diaphyseal portions of the humeri, femora, tibiae, fibulae, ulnae and radii (Figs. 2-A and 3-A). There was an abrupt demarcation between the involved and normal bone. The base of the skull and the inner table of the frontal bone showed slight thickening (Fig. 4). There was an old transcervical fracture of the left femur with a bone peg through the fracture site. The chest, ribs, lumbar vertebrae, hands and feet were normal. Serial roentgenograms made during the next twenty-two years showed only slight progression in the distal ends of the radii and ulnae, but no change in any of the other bones (Figs. 2-B and 3-B).

Pathological findings: Dr. Weldon K. Bullock, surgical pathologist at the Los Angeles County Hospital, in describing the three biopsy specimens noted the following. The specimen of the left humerus taken in 1934 showed dense cortical bone in which there were marked variations in the size of Volkmann's canals. In some parts the lamellations were well defined by smooth resting cement lines, while in other areas the reversal cement lines were prominent, outlining numerous breccia. The microscopic section of the femur (Fig. 5), made in 1953, showed the bone essentially the same as in 1934. The bone marrow is absent in these specimens. A bone specimen taken from the osteotomy site in 1954 showed a reparative process with hyperaemic deossification. Although the bone has cancellous appearance, the basic dense sclerosis remains. The bone marrow was fatty and without fibrosis. The blood vessels in all the sections were normal.

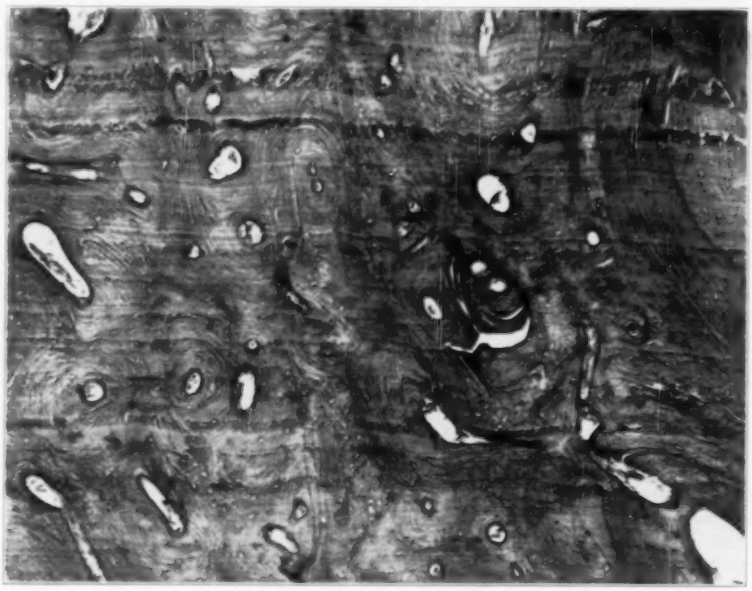

FIG. 5

Los Angeles County Hospital Slide No. D 5253 B, showing the characteristic histological appearance of the lesion.

DISCUSSION

The pathological, clinical, and roentgenographic features of Engelmann's disease, or progressive diaphyseal dysplasia, were recently reviewed and summarized by Griffiths. There now are recorded seventeen proved and five probable instances of this entity. Most of the features of the present case are fairly characteristic: bone pain in youth, dense cortical bone which produces thickening of the diaphyses [9], normal marrow and peripheral blood elements, and normal blood chemistry. In contrast to some of the other cases, this patient's general physical and muscular development were normal with no deformities. His fractures followed major accidents.

What has been of particular interest, and the primary reason for reporting this case, is the negligible progression of the disease during twenty-two years. The progression described in the previously reported cases was almost exclusively in children. Papers by Gillespie and Mussey, and Gulledge and White each reported slight progression in a child who had been followed about two years.

Ribbing investigated osseous changes in four siblings, of whom one had had symptoms for over six years. In one of his cases there was marked progression, in two there was slight progression, and in one there was none. He was not certain that the disease was Engelmann's because of the hereditary aspects. Neuhauser and associates followed four

children for from five to nine years and reported slight to extraordinary progression in the bone changes in all of them. Ortolani and Castagnari followed a six-year-old girl for twenty years, during which time all of the major long bones became involved.

Only three other adults have been followed. Stronge and McDowell reported no progression in the bone changes in a twenty-eight-year-old man observed for three and one-half years. Griffiths thought that the disease progressed in a twenty-nine-year-old woman whom he had followed for six years, but did not offer roentgenographic evidence. Ortolani and Castagnari followed a nineteen-year-old man for nineteen years and observed no change.

In most patients followed during childhood slight to marked progression has been reported. In adulthood, as in the present case, the disease does not appear to progress significantly.

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Sterling Bunnell

In Appreciation

When I was a young surgeon just developing an interest in surgery of the hand, I was introduced to Dr. Bunnell by Allen Kanavel during a meeting in San Francisco. I was most cordially received and invited to visit him in his operating room the next morning. A very enjoyable and profitable time was spent watching operations skillfully performed and accompanied by discussions of principles and rationale of the procedures carried out. Many of the details of Sterling Bunnell's explanations I am afraid were too far advanced for me at the time, but later experience has increased my understanding and appreciation of them. That evening I was invited to his home as one of his dinner guests. We arrived just at dusk and Dr. and Mrs. Bunnell took us out to see his garden before it became completely dark. I have only a hazy recollection of the garden except that it was a natural sort of place, not superlandscaped, and strange bushes and trees and boulders were everywhere. In one corner among the boulders was a large semiovoid object which proved to be an enormous turtle which lived in Dr. Bunnell's garden. This reptile formed the opening gambit for our after-dinner conversation concerning turtles and snakes and the fauna of the desert, subjects on which Bunnell was an authority. I was extremely interested and most impressed; my first love had been biology and I thought I was reasonably well informed in comparative anatomy but Bunnell's knowledge so far outstripped mine that I felt humble indeed.

Sterling Bunnell was a naturalist in the true sense of the word. All life interested him—an interest which might have led him into any one of a number of fields of endeavour. Why he chose surgery and finally made surgery of the hand his special field no one can tell; perhaps he could not have told, himself. Undoubtedly his appreciation of the life processes and of the action and interaction of muscles and parts and of the adaptation of parts to function or function to parts, as seen in comparative anatomy, focused his attention on the hand. Perhaps his experience in World War I made him realize this was a neglected field in surgery. His first publication on nerve and tendon repair of the hand appeared in 1918; following this came numerous papers dealing largely with reconstructive surgery of the hand.

To enumerate the areas of reconstructive surgery of the hand in which Bunnell's influence was felt would be to copy the index of his volume *Surgery of the Hand*. There was scarcely any field in hand surgery in which Dr. Bunnell did not make contributions. Possibly his major efforts and contributions were in the surgical repair of tendon injuries and here his approach, on a strictly physiological basis, has withstood the test of time. His boldness in advocating tendon grafts, in a day when such surgery was even more fraught with the hazards of infection and adhesions than today, forced others to appreciate the value of his technique. Gentle handling of tissues and the use of fine, non-irritant suture material were constantly emphasized. As a general surgeon trained in the techniques of surgery in the early 1900's he soon realized that methods of handling tissues suitable for hernia repair were not adequate for the treatment of injuries of the hand. It required an understanding of healing processes and a recognition of the fact that healing can take place only if tissues have not been traumatized. One must have a histological concept of tissue or a microscopic concept. This concept he developed into what he termed an *atraumatic technique*, a phrase which, first coined in 1921, has become almost the shibboleth of the hand surgeon.

Bunnell's study of the action of the thumb, most ingeniously demonstrated in photographs, has given us a logical concept for restitution of function when the thenar

musculature has been irreparably paralyzed. The various techniques in use today for restoring opposition of the thumb are all based upon this concept.

His appreciation of function in a part kept him from going astray in procedures the value of which was only cosmetic or merely to demonstrate surgical virtuosity. This can be seen in his approach to thumb reconstruction. When possible, grasp should be restored by use of local elements, by deepening the cleft if the metacarpal stump is long enough. When such cannot be accomplished and when a local digit is available, transfer of this with its neurovascular pedicle to replace the thumb is preferable to tube flaps and bone grafts which lack sensation and often motion. A short thumb with sensation is preferable to a longer but insensitive peg.

"In hand repair, we should recognize our limitation and not hope to make a perfect hand out of a cicatricial wreck." This statement did not imply a hopeless or defeatist attitude toward any hand no matter how hopeless it might seem. What it did imply was that one should consider the hand from the standpoint of function and of the material left with which one has to work. If nothing more, one should attempt to restore grasp and sensation to whatever degree the hand remnants permitted. With just a little grasp and a little sensation a hand is useful.

Sterling Bunnell attained a goal which every surgeon wishes to attain, that is, that his work shall live and progress after his passing. Besides Bunnell's associates who carry on his tradition, there is a large group of surgeons now scattered throughout the country, trained in the nine hand centers established by Bunnell in Army Hospitals during World War II. These centers, to which Bunnell gave a great deal of time and effort, served to establish surgery of the hand as an entity, whereas it had previously been looked upon as a mixture of orthopaedic surgery, plastic surgery, and neurosurgery. Bunnell's efforts were also recognized abroad and with the publication of his *Surgery of the Hand*, hand surgery became firmly established.

This encyclopedic volume, twice revised, is now a standard reference work for all interested in this field. It is indeed interesting that this generation has seen two such influential books in surgery of the hand — Kanavel's *Infections of the Hand*, and Bunnell's *Surgery of the Hand*.

Bunnell was no defeatist, as Howard has noted in his excellent obituary. Although he gave the name of no-man's-land to a particular area of the fingers where flexor tendons should not be repaired primarily, one has the feeling that he would still prefer primary repair in suitable cases. His method of repair in these cases has been described in detail and it is based on a real appreciation of tendon physiology and healing. Possibly only the difficulties in carrying out the proper atraumatic technique by those not especially experienced in this surgery led him to caution against repair in no-man's-land. However that may be, one has the feeling that if he had been younger, this problem would have been a challenge which he would have met.

The matter of nerve grafts for restoring sensation to the hands and digits was likewise a field in which he was pioneer. They offer the only hope of restoration in many badly damaged hands, and while they do not offer a chance of complete success neither does nerve suture.

Certainly the digital nerves are very suitable for this type of repair and the results in larger nerve trunks by means of Bunnell's cable grafts have been encouraging. He has shown us that such grafts may function; it remains for us to work out the details which will make restitution more certain.

Bunnell was quick to appreciate new ideas and procedures and to put them to the test of judgement and trial. He had a young mind, and was always ready to listen to young men and discuss their problems sympathetically with them.

If one were to try to sum in a few words the contribution of Bunnell to American surgery, it might be something like this: his contribution has been the stimulus he has

given to the development of surgery of the hand by demonstrating that with an appreciation of the function of the hand and by a careful atraumatic technique and a respect for delicate living tissues, reconstruction procedures may be carried out with success.

Michael L. Mason

Dr. Sterling Bunnell was a great surgeon, an outstanding teacher of hand surgery, and an inspiration to the world in both these regards. Many of us who knew him well, feel that Bunnell's greatness was partly due to his interest in other creatures besides man. He was described to me by one of his outdoor friends as first a naturalist, second a hunter and fisherman. In 1903, as ornithologist for the San Francisco Academy of Sciences, he with a group of other scientists went by sailboat to the Revilligegedo Islands in the Pacific, off the Mexican Coast, where he made extensive studies of bird life. He always enjoyed hunting, both animals and birds, large and small, and catching fish with his friends, but the golden time of the day for his fellow sportsmen was in the evening when he would sit around the camp fire and for hours describe the various types of snakes, lizards, fish, mammals, birds, and other living forms, and tell of the natural history of the process of evolution—why each were so alike and yet so different. He had collected from childhood a complete assortment of California birds, which he had mounted, and finally sold to the Philadelphia Museum when he entered medical school. His love of nature and of natural surroundings, including life in the air as well as on the earth, and his knowledge of living things is portrayed in the first chapter of *Surgery of the Hand*, "Phylogeny and Comparative Anatomy".

Probably his greatest outdoor love was bird hunting, and even in this he had a specialty; he loved to hunt ducks more than any other creature. Those of us who have spent many hours in the blind watching ducks come and go can appreciate the interest this would create in a man of his investigative mind. There are few sights as stimulating as ducks coming into a blind, turning, winging in, landing, sitting, taking off, or changing their minds because something in the blind is not just right. I have been told that there were very few occasions when Dr. Bunnell would not respond when called upon to teach or advance the art of hand surgery, but at times he would be a bit annoyed if this occurred at the opening of duck-hunting season. He was an expert shot, but his greatest interest was how the duck flew—how it took off, landed, turned to right or to left, and how it was able to land without apparent effort or movement of wings.

This brings up another interest of Dr. Bunnell—aviation. After the World War I, he learned to fly, and apparently it gave him a great thrill to conquer the air, for even as a boy he was filled with envy as to "how and why a bird can fly, but not I". After years of flying, he finally crashed in 1926, breaking his hip; this ended his private flying.

In 1930 he published an extremely well documented article on the "Aeronautics of Bird Flight". The mysteries of soaring birds were explained in this article as well as how man learned to operate a glider by studying how the birds picked the correct air currents to carry them aloft and keep them at a restful altitude. He explained why the gliding birds had much less muscle volume than the birds which fly at high speed.

In the last few years of his life Dr. Bunnell was an ardent quail hunter. He had suffered from stiffness of one hip which necessitated that he use a staff or stick while in rough country. It was a sight never to be forgotten to see a quail flush, the staff discarded, the gun brought to bear, and another quail for dinner! Being an ardent sportsman, he also spent considerable time and effort in fishing. Of course, he preferred trout (in a mountain stream), for there there was always action and great activity. He was addicted to the dry fly in fast water for it called for great alertness and concentration—both parts of his nature. In fishing and hunting, as well as in work, he was always interested in teaching

those who wanted to learn. Within the last year, a boy of fifteen years who lives in Jackson Hole, Wyoming, asked me if I knew Dr. Bunnell, stating that he had been there the year before and had spent much time teaching him to fish, telling him of the development of the fish, and other things of interest such as their habits, where to find them, and how to catch them. This lad had the same respect, the same admiration, for Dr. Bunnell as did the residents and the fellows he trained in surgery.

Dr. Bunnell was consultant to the Alaska Department of Health. I am quite sure he valued this honor as much as many he had received, as it took him to a land of vast wilderness areas. On one of his trips to Alaska as consultant a great deal of his spare time was spent photographing the Alaskan brown bear. This resulted in some interesting experiences with this formidable and largest of bears, which Dr. Philip H. Moore, of Sitka, Alaska, a member of the party with Dr. Bunnell has related to me. It was apparently quite a surprise to Dr. Bunnell that all bears are not like the black bear; the brown bear does not always run in the other direction. On one occasion, after four trips around a tree with a brown bear close behind, he decided to take to the tree and leave the ground to the bear. On another occasion, after a day of hunting and fishing in the mountains of Alaska, the tent was pitched for the night on the side of a steep mountain; after dinner, while sitting around the camp fire, Dr. Bunnell was telling of the early days of surgery of the hand. While he was talking a rather severe earthquake occurred, and large boulders came down the side of the mountain past the camp site, and into the lake. He was unconcerned about this event as though he had been sitting in his parlour in San Francisco. Nothing in Nature or the outdoors seemed to disturb him.

In his passing we have lost a great surgeon; few have realized that science has also lost a great naturalist, whose understanding of all Nature aided him in his ability to investigate and contribute so much to the surgery of the hand in man.

Walter G. Graham

It is hardly necessary to recount Sterling Bunnell's accomplishments in the field of reconstructive surgery to readers of an orthopaedic journal. His contributions covered the whole field, but he will be best remembered for the development of surgery of the hand which he called the "jewelry of orthopaedics."

His predominant trait was determination and it carried through all of his activities whether work or play. Expressing it in the operating room as surgical drive, he constantly instilled in his associates a feeling that he was being propelled by a never-ending force. For years this resulted in extraordinary physical feats, working long hours, never stopping for lunch, jogging up the five flights of stairs to the operating room rather than waiting for the elevator, and then, when the week's work was over, racing to the duck club or a deer hunt or to fish in the streams of northern California.

This resoluteness, sometimes bordering upon stubbornness, depending upon whether or not you were in agreement with his ideas, was shown in his characteristic method of working out a problem. He was not prone to discuss pros and cons but rather after studious concentration over the points in question to state his views.

His judgment was given in a positive manner and discussion was of little avail unless some important new fact was disclosed to change the basic factors. He abhorred the thinking-out-loud procedures so common in committee or organization meetings and, therefore, was reluctant to enter into such discussions. He had the ability to concentrate his whole effort on a problem, excluding all others and staying with it until finished. Once solved or the immediate question settled, he could then go on to another and another, each time with a fresh approach. In studying results of a procedure he was more critical of his own work than of others and never seemed satisfied with anything less than perfection.

In talking with patients he was brief, concise, and positive. There was no place for bedside discussion of various forms of treatment. He did not like snap diagnoses or decisions but wanted all of the facts. He felt that it was the surgeon's duty to study the patient's problem in all of its details, then make the decision and recommend it to the patient. Since the patient had no background of knowledge to make a choice, he felt that it was the surgeon's duty and obligation to make it for him. His recommendation was then given in a clear, unambiguous, and succinct way. There was no doubt of the firmness of his belief. His way of studying and examining a problem however resulted in gaining the patient's confidence so that seldom, if ever, was his recommendation refused.

His style in writing tended to conciseness; he would avoid any excess of words. He used relatively short sentences, strong verbs, and few adjectives. He used epigrams to stress a point and "no-man's-land," "pernicious median longitudinal incision," and "atraumatic technique" are all familiar to his readers. A typical saying was his answer to a too positive statement of mine, "Never say never in Medicine." In stressing the importance of a tourniquet in dissection of the hand he used the expression, "You can't fix a watch in a bottle of ink."

He disliked waste of any sort, either words, time, motions, even dressing materials and adhesive. I well recall one of the first days in his office, being shown how to bandage a finger with the fewest motions, the minimum turns of bandage, and the least amount of adhesive. This conservation of motion was almost noticeable in the operating room where every motion must be necessary and then made with the minimum effort. He long ago described visiting a lapidary to learn how to use his hands more skillfully and with minimum motion. Just as his determination was carried over into non-professional life, so was this fetish of wasted motion. He always put his arm through vest and coat at the same time to save motion and has been known to swallow a spoonful of instant coffee powder thus avoiding the wasted time of dilution, stirring, and dissolving.

His surgical technique depended upon a most detailed knowledge of anatomy, extreme skill in dissection, and ability to think and solve the principle of the problem, leaving the details to be filled in almost automatically. Many of his procedures were difficult for an observer to follow, and reading the text of *Surgery of the Hand* is also difficult. There is no attempt to describe and illustrate the hundreds of surgical details in any procedure. The principle is broadly outlined and the observer or reader must work out the rest for himself. He always felt that reconstructive surgery was for the experienced surgeon and therefore it was unnecessary to go into minute details that every surgeon ought to know. His knowledge of anatomy was unbelievable and this combined with a dextrous way with a scalpel made complicated procedures almost trivial. He had no use for blunt scissor dissection and especially detested wiping of structures with gauze. To watch him do an axillary or radical neck dissection, done almost entirely with a knife, more than compensated for the constant pressure he put on the surgical team through the whole procedure.

His interest in animals was life long. As a boy he collected and mounted birds and other animals, and became a competent professional collector. Any and all animals were of interest. Every visitor to his home in San Francisco will recall his pets. The iguana, the tortoises, and especially the baby alligators that came up to eat when they heard his footsteps on the edge of the pond. One such pet was a large owl caught in a humane trap made from a piece of shoelace and two mouse traps, which lived in a cage in the bathroom of his apartment. This interest in animal collection resulted in some unusual work in the shop at the office. One could find him, at times between patients, fashioning an exercise wheel for a kangaroo rat or a trap for mice to be used on the next trip to the desert. His study of animals was thorough and through this came his detailed understanding of anatomy and function.

Sterling Bunnell was not a man for many to know intimately. He did not discuss his personal feelings or aspirations and was reticent to the point of shyness in discussing him-

self in any way. His whole interest centered in his work, which he would show and demonstrate without hesitation; in personal things he was modest to the extreme. He disliked pompous speeches, actions, and words. Politically he was an old-time conservative pre-Roosevelt Republican.

His approach to surgical problems was practical in the extreme. A method must work or it was of no use. He was not interested, as such, in basic research, but insisted on a practical application of knowledge to the problems encountered in everyday practice. This matter-of-fact practical approach was carried over into his personal philosophy. He was not sympathetic in nature, and personally being indifferent to pleasure or pain, he admired stoicism in others and was apt to be short with those who gave in to their feelings and emotions without sufficient cause.

He loved the outdoors, and probably spent many of his most enjoyable hours hunting or fishing. These were not vacation trips. One personal experience made me wish for the comparatively restful and less strenuous office routine. Indefatigable, he hunted and fished as he worked, with an all-out effort, yet planned to the most minute detail. He had a large box holding a thousand and one items of possible use on a trip. Upon his return, the first order was to replenish the stock and add to it those items which he found would have been of some help. Knowing animal habits made him a good hunter and fisherman and to accompany him was to enjoy a postgraduate course in geology, forestry, botany, and comparative anatomy.

Sterling Bunnell was born, reared and educated in San Francisco where he lived his entire life. Here in a city of pioneer spirit, itself only thirty years old when he was born, he followed the pioneer's trail into the realm of surgery and opened up an entire new field, surgery of the hand, with which his name will ever be synonymous. San Franciscans have been described as "a stony people, astonishingly like New Englanders, stubborn, proud, willful, self-contained, tenacious, fiercely independent." He was a true son of San Francisco.

On the State Capitol Building in California is engraved this saying, "Bring me men to match my mountains." He matched them.

Joseph H. Boyes

Proceedings

THE JAPANESE SOCIETY OF ORTHOPAEDIC SURGERY

PREPARED BY PROFESSOR EISHI KONDO, KYOTO, JAPAN

The Twenty-Ninth Annual Meeting of The Japanese Society of Orthopaedic Surgery was held in Yokohama on April 3, 4, and 5, 1956, under the presidency of Dr. Shiro Mizumachi, Professor of Orthopaedic Surgery, Yokohama University Medical School.

Dr. Hiroshi Matsumaru, Professor of Orthopaedic Surgery, Nagoya University Medical School, was elected President for the next Annual Meeting to be held April 11, 12, and 13, 1957, at Nagoya City.

Summaries of the papers presented during the Scientific Sessions of the Twenty-Ninth Meeting are as follows:

Presidential Address. PROF. S. MIZUMACHI (Yokohama) discussed injuries incurred during athletic activities. He felt that inexperience is the most common cause of these injuries and that fatigue is the next most common cause. To determine the presence of fatigue, he had measured the threshold voltage required to produce phosphene electrically.

Osteogenic Sarcoma. DR. S. TORIYAMA, DR. I. TANGE, and DR. M. URABE (Tokyo).

Bone Tumors. DR. I. MAEYANA, DR. M. TOMISHIGE, DR. T. SHIROMA, and DR. K. GOTO (Fukuoka) reported their clinical observations in 497 cases of bone tumors.

A Clinical Study of an Endemic Bone Disease. DR. I. TAGA, DR. I. MURATA, and DR. N. HAGINO (Toyama) reported fifty cases of an endemic bone disease seen in Toyama Prefecture. This disease resembled osteomalacia in its symptomatic manifestations but was otherwise quite different.

The Effects of Orthopaedic Surgery upon the Human Body. DR. J. KAWAMURA (Tokyo) had studied a series of twenty patients treated by various operations in order to determine the effects of surgery upon the human body and to find the best means of counteracting these effects.

A Cicatricial Contracture of the Hand. DR. T. MOROTOMI, DR. K. HISAMOTO, DR. T. NAKAMURA, and DR. I. FUKUI (Hirosaki) had conducted experiments in which cicatricial contractures had been produced in rabbits by electrical burns. To treat cicatricial contracture of the hand they advocated immediate excision and the application of a free skin graft with a thick corium and with numerous holes made by the insertion of a needle from the corium side. They reported their experiences with this method during the previous three years.

Plastic Procedures on the Skin of the Hand. DR. T. TAJIMA and DR. R. YONEYAMA (Niigata) described their basic operative principles, which had been derived from the experiences of Bunnell as well as their own experiences, and reported their end results.

Repair of Tendon Ruptures in the Hand. DR. T. TAJIMA and DR. Y. WATANABE (Niigata) reported their experience in this field. Of forty-eight patients with extensor-tendon ruptures, thirty-nine had excellent results. Of twenty-one patients with flexor-tendon ruptures, none had excellent results and many had poor results; nevertheless, the over-all results in this group were much better than those obtained in former years.

Experimental Studies on Core Materials for Artificial Tendons. DR. T. IKAI (Nagoya) described experiments in which rabbit tissue had been tested in order to determine its biological response to silk suture, silk tegusu, 18.8 stainless-steel wire, nylon, and Vitallium. Of these five materials stainless-steel wire and Vitallium produced the most favorable physiological reactions, these reactions being almost the same as those produced by natural tendon.

Photo-electric Studies on Hip-Joint Arthrodesis. DR. M. TAKATA (Tottori) on the basis of photo-electric studies, claimed that the method of arthrodesis which produces the best results is the ischiofemoral method. Following use of this method, especially when it is done by Brittain's technique, better femoral movement is obtained and there are fewer instances of adduction contracture.

An Experimental Study on Artificial Joints Made of Plastic. DR. K. TSUGE, DR. M. MIYAMOTO,

and Dr. T. Fukuma (Okayama) described their experimental work on the formation of artificial joint capsules for use following arthroplasty. In a series of rabbits the cartilage and joint capsule had been removed from the knee and an artificial capsule made of polyethylene had been inserted. Almost no tissue stimulation had been produced by the polyethylene. In the group of rabbits in which casts had been used, the artificial capsules had become surrounded by connective tissue after two weeks, cartilage cells had appeared after two or three weeks, and synovial cells had appeared after four or five weeks. In the group in which casts had not been used, the inner surfaces of the artificial capsules had not become covered by connective tissue until a little later.

Studies on a New Type of Absorbable Hemostatic Bone Wax. Dr. K. Nakano, Dr. K. Hirohata, Dr. T. Nagano, and Dr. M. Sakata (Kobe), basing their work on the report of J. R. George and his co-workers, had devised a new type of absorbable bone wax for use in orthopaedic operations. This wax contains 35 per cent oxidized cellulose, 45 per cent carbowax, and 20 per cent polyethylene glycol. Histological examination of tissues from rabbits and patients in whom the wax had been used had revealed that tissue reaction rarely occurred, that the wax was rapidly absorbed, that callus formation was not prevented, and that more favorable styptic action was obtained.

Studies on the Trabeculae of Human Bone. Dr. I. Tochinai, Dr. M. Ishii, Dr. K. Koizumi, Dr. Y. Sato, Dr. Y. Ichinohe, Dr. T. Yamazaki, Dr. E. Hohida, and Dr. S. Tozima (Morioka) reported the findings of their comparative-anatomy study on the architectural structure of bone in humans and in different animals and fowls.

Study of Low-Frequency Pulse Rectangular Polarization, Especially Spinal Polarization. Dr. J. Suzuki, Dr. B. Ishibashi, Dr. H. Okuda, Dr. Y. Ishikawa, Dr. K. Sakamaki, Dr. Y. Kanesaka, and Dr. G. Ogawa (Chiba) investigated the effect on reflex action of low-frequency rectangular pulse spinal polarization (frequency 1,000 cycles per second, duration-pause ratio 2:1, three to five milliamperes). The following observations were made: (1) during polarization, the average frequency of the impulses remains constant; (2) in the portion under the anode, the impulses are increased, and in the portion under the cathode they are inhibited; and (3) following anodal polarization the refractory period of synapse is shortened. These observations of the authors are in accordance with those of Dr. M. Suzuki, who advocated use of polarization in order to obtain shortening of the synapse period. Myographic studies indicated that synchronization voltage is desynchronized after polarization. In the authors' series of seventy-four patients with residual poliomyelitic paralysis, the following results were obtained by the use of polarization: good, 22.9 per cent; fair, 61.4 per cent; and poor, 15.7 per cent.

Study on the Occurrence of Bone Tuberculosis. Dr. S. Nishi, Dr. M. Kikuno, Dr. T. Sato, and Dr. K. Ebata (Tokyo) stated that neither severe trauma, such as fracture, nor destruction of bone by means of a strong direct electrical current can cause tuberculosis of the bone. Use of a weak direct electrical current is also ineffective, unless the bone marrow has been invaded by tubercle bacilli. If the bone marrow has been invaded, however, repeated application of a weak current can cause a circulatory disturbance which will result in the formation of a tuberculous node. The authors' inference is that in a bone in which there are inactivated latent bacilli, minor trauma repeatedly applied at a certain interval may cause the development of tuberculosis.

Experimental Studies on Joint Tuberculosis in Guinea Pigs. Dr. H. Kasuga and Dr. T. Hara (Tokyo) had injected one milligram of live tubercle bacilli of Aoyama B strain, suspended in one cubic centimeter of liquid paraffin, into the knee joints of guinea pigs which had previously been infected with tuberculosis. Non-specific inflammatory findings in the synovial membranes were observed in the first two weeks, and predominantly exudative tuberculous lesions in the synovial membranes, menisci, and bone marrow adjacent to the condyles was observed after four to eight weeks. Epithelium cells in great numbers appeared after ten weeks, and calcification in necrotic lesions was seen after twenty-four to twenty-eight weeks. Obvious atrophy of bone trabeculae in the epiphyseal portion developed in thirty-two weeks.

Early Diagnosis of Joint Tuberculosis. Dr. K. Yahashi, Dr. M. Yamatoku, Dr. K. Yamamoto, Dr. I. Koizumi, Dr. T. Ishizuka, and Dr. K. Miyoshi (Tokyo) had made a comparative study of various clinical methods for obtaining early diagnosis of joint tuberculosis. In forty cases of possible joint tuberculosis they had applied the following methods: roentgenography including tomography; biopsy; study of the focal tuberculin reaction; determination of the blood picture, serum protein, and erythrocyte sedimentation rate; use of radioactive isotopes (P^{32} and C^{45}); and microscopic study including culture and fluoromicroscopic study of bacilli obtained at biopsy from foci or regional lymph nodes. The most reliable method was found to be roentgenography combined with bacteriological culture or fluoromicroscopic study of material obtained at biopsy.

Histochemical Studies of Tuberculous Lesions of the Bones and Joints (First Report). Dr. Y. Akahoshi, Dr. C. Yamamoto, Dr. K. Asada, Dr. M. Sato, Dr. N. Hirose, and Dr. H. Fujita (Kyoto) had made histochemical studies of bone and joint tissue in 104 cases of tuberculosis. The methods used had included Takamatsu and Akahoshi's method of determining the alkaline phosphatase reaction, determination of the reaction to para-aminosalicylic acid, metachromatic (pH 2.5, 4.1, 7.0) hematoxylin-eosin staining, Mallory's staining, van Gieson's staining, determination of the calcium reaction, and silver fiber staining. The histochemical findings varied according to the clinical and pathological nature of the tuberculous processes. In the tissues surrounding the tuberculous lesions there was new-bone formation as a result of metaplasia of young mesenchymal cells and hypertrophic cartilage with abundant chondroproteins, both these conditions indicating fairly good powers of regeneration.

Experimental Research on Accelerating Factors in the Development of Tuberculous Lesions. Dr. T. Tamaki and Dr. Y. Furukawa (Nagasaki) had made a study in which 0.1 milligram of tubercle bacilli in homogenized emulsion had been injected into the auricular veins of rabbits and three weeks later two milligrams of hydrocortisone and 4,000 H.U.M. of trypsilin had been injected into the marrow cavities at the lower end of the femur and upper end of the tibia. Seven or eight weeks after the second injection, a tuberculous lesion had been observed (both by the naked eye and by microscopic examination) at the site of inoculation in each animal. Seven months later new-bone trabeculae and fibrous marrow tissue had formed and the lesion had healed.

Influence of Blood Serum on Tissue Respiration in Patients with Joint Tuberculosis. Dr. A. Miyazaki and Dr. T. Samejima (Kagoshima) reported studies in which pieces of rabbit kidney, freed of blood and washed with saline solution, had been suspended in the blood serum of a patient with bone tuberculosis. The oxygen intake had been measured by Warburg's method. The results appeared to confirm the authors' belief that some factor must be present in the blood serum of a tuberculosis patient which disturbs cell metabolism.

End-Result Study of Operative Treatment Designed to Restore Movement in Patients with Joint Tuberculosis. Dr. E. Marumo, Dr. M. Utsubo, Dr. F. Sawada, and Dr. N. Ando (Tokyo) had performed operations in sixty-six cases of tuberculosis of the elbow, knee, or hip. The types of operation used had been (1) typical joint resection, (2) non-typical joint resection, (3) arthroplasty with the insertion of viable fascia, and (4) wide resection of the joint with insertion of a prosthesis. Follow-up had been maintained for from six months to five years. The worst results in the series had occurred in the patients treated by typical joint resection. In the patients with knee-joint tuberculosis, the best results had been obtained by arthroplasty. In all caes joint movement had been retained. The length of time before walking with weight-bearing had been resumed was three to four months in the cases involving the hip and four to five months in the cases involving the knee.

Chemotherapy in Joint Tuberculosis. Streptomycin, Para-aminosalicylic Acid, and Isonicotinic Acid Hydrazide Administered by Intravenous Drip. Dr. K. Namba, Dr. T. Murata, and Dr. K. Mihara (Nagasaki) described use of a solution consisting of one milligram of streptomycin, ten or fifteen milligrams of para-aminosalicylic acid, and 0.1 gram of isonicotinic acid hydrazide dissolved in Ringer's solution. In each case this solution was administered intravenously by drip twice a week. Blood levels of the drugs were determined following administration. Clinical data, including such factors as hemoglobin, red-blood cell count, white-blood cell count, erythrocyte sedimentation rate, and body weight, were also determined in thirteen cases. It was found that very high blood levels and prolonged efficacy were obtained, results which had not been possible by other methods. The authors concluded that this method was very safe and effective.

Study of Joint Tuberculosis in Guinea Pigs Following Resection and Insertion of an Interposed Membrane. Dr. Y. Itami, Dr. Y. Iwase, and Dr. T. Otani (Tokyo) had inserted various types of membrane into the resected joint spaces of guinea pigs. On the basis of the findings of roentgenographic and other examinations, they had concluded that the best method of treatment is the insertion of viable fascia, this material being the most easily obtainable. They added that associated chemotherapy is essential.

Pathohistological Study of the Efficacy of Therapeutic Treatment in Joint Tuberculosis. Dr. T. Ikari, Dr. M. Kamada, Dr. K. Kaneko, and Dr. Nakagawa (Sendai) had made histopathological studies of autopsy specimens from sixty-one patients who had not received chemotherapy and from eighty patients who had received chemotherapy. In the latter specimens, leukocytes and plasmacytes had been found in the foci, a finding seldom observed in the specimens from the patients not treated by chemotherapy. Also in the specimens from the patients treated by drugs, the presence of Langhans' macrocytes had been observed. In tuberculous patients these cells appear as a foreign-body reaction. If increased doses of anti-

biotics are given, syncytiophagy and sometime synctiolysis will occur. During convalescence these cells will disappear entirely as a result of phagocytosis. The cells most active in promoting healing are the fibrocytes. Chemotherapy cannot prevent development of tuberculous nodes, but it does prevent caseation of the foci. It causes extraction of cholesterol from and condensation of the caseating foci and expedites cavity formation. When the caseous foci contain sequestra and necrotized cartilage, it is almost impossible to produce cure by inducing encapsulation. At present it is difficult to cure tuberculosis of the joints by means of medicaments alone; foci containing tubercula, sequestra, and necrotized cartilage must still be extirpated by surgical operation combined with the continuing application of chemotherapy.

The Efficacy of Zinc Oxide Ointment for Tuberculous Ulcers. Dr. S. Hiraoka (Tokyo) had studied experimentally the efficacy of zinc oxide ointment in the treatment of tuberculous ulcers and fistulae. Some favorable effect was demonstrated, although the healing effect was inferior to that obtained by streptomycin.

Cold Abscesses in Tuberculous Spondylitis. Dr. S. Sakai and Dr. A. Kawata (Osaka) on the basis of surgical, roentgenographic, pathohistological, and bacteriological studies, discussed the use of cold abscesses in the treatment of spondylitis.

An Attempt to Appreciate the Severity of Symptoms of Tuberculous Spondylitis. Dr. T. Nakamura, Dr. F. Kondo, Dr. T. Tachibana, Dr. H. Midamaru, and Dr. K. Terayama (Tokyo).

Clinical Observations on the Occurrence and Progress of Hip-Joint Tuberculosis. Dr. T. Ito (Ube) had made a clinical study of sixty-six cases of hip-joint tuberculosis. On the basis of the patterns of development of the disease, as seen at surgery and as demonstrated by roentgenogram, the cases were divided into two groups: (1) those in which the primary focus was located in the acetabular roof and (2) those in which it was located in the head and neck of the femur. On the basis of further localization of the primary focus, the first group was then subdivided into four subgroups and the second group, into six subgroups. This system of classification seems to be valuable in the determination of both the treatment and the prognosis.

Arthrodesis in Hip-Joint Tuberculosis. Dr. N. Morisaki, Dr. M. Matsunaga, Dr. H. Kurihara, Dr. T. Iijima, and Dr. K. Kitagawa (Tokyo) reported their experiences with ischiofemoral and wide-abduction arthrodesis, emphasizing the difference in indications for the two methods.

Results of Operative Treatment of Hip-Joint Tuberculosis. Dr. K. Arihara, Dr. H. Hashimoto, Dr. S. Morita, and Dr. T. Matsumura (Kyoto) had treated fifty-six patients by means of (1) cleaning of the foci (forty-one cases), (2) Trumble's arthrodesis (seven cases), (3) subtrochanteric osteotomy (four cases), and (4) scraping out of the abscess and fistula (four cases). The length of follow-up had ranged from one year to seven years. The results of cleaning of the foci and of arthrodesis had been particularly satisfactory. Forty-six of the patients had sufficiently good results so that they could attend school and be otherwise active. Six patients showed only slight improvement, and the remaining four patients had died. In some of the patients in whom the lesion had been cured, the range of motion of the involved joint was not satisfactory and there was diminished weight-bearing and development of adduction deformity. Because the postoperative range of motion obtained was greatest in the younger patients, the authors concluded that cleaning of the foci was more suitable for the younger patients while arthrodesis was more suitable for adults.

Skin Incisions in Operative Procedures on the Ankle Joint. Dr. K. Yamada, Dr. S. Hattori, and Dr. N. Kato (Tokushima) described an approach in which two parallel longitudinal incisions are made on the frontal aspect of the ankle joint. They had used this approach in several cases and reported it has several advantages.

The Frame Prosthesis and Apparatus. Dr. T. Oneda, Dr. T. Fukuhara, Dr. Y. Kikuchi, and Dr. M. Kitazima (Maebashi), noting that even in the suction socket disturbances of the prosthesis are not completely eliminated, had designed frame sockets for above-the-knee and below-the-knee prostheses.

Structure of Supporting Apparatus for Hip, Knee, or Ankle Joint. Dr. I. Yasuda, Dr. K. Okada, Dr. H. Tasaka, Dr. T. Sasada, and Dr. S. Ko (Kyoto) had studied the problem of providing support for the joints of the lower limb by means of the electric piesimeter. They had designed an apparatus for the hip joint which fixes the hip but leaves the knee freely movable.

Improvement of Spinal Suspension on an Inclined Bed. Dr. T. Takahashi and Dr. K. Mori (Fukushima) had studied experimentally and clinically a method of spinal traction in which rollers are

attached to the undersurface of a board placed beneath the mattress. This method overcomes any untoward force of friction and results in constant traction, greater ease in care, and less danger of oedema, the necessary inclination of the bed being less than that required by other methods.

The Treatment of Extrapyramidal Syndrome by Blocking of the Lentiform Nucleus by Injection of Moljodol and Eax. Dr. H. Katsumata and Dr. T. Hiramoto (Kyoto) reported that the effect of these injections in patients with cerebral spastic palsy, epilepsy, and parkinsonism appeared to be favorable.

Electro-encephalographic Studies of Children with Cerebral Palsy Made During Sleep. Dr. K. Kitamura and Dr. K. Sato (Tokyo) had made electro-encephalographic studies of 1,808 children with cerebral palsy. The results had been compared with those of pneumo-encephalographic studies of fifty-three children with cerebral palsy. Foci showing asymmetrical diminution or abolition of sleep spindles were found in thirty-eight cases, and spike discharges were observed in sixty-three cases. The former were considered to be of significant aid in localizing the cerebral lesions, for they also appeared in the portion of the pneumo-encephalogram which showed the pathological symptoms. Six-per-second and fourteen-per-second positive spike discharges were observed in seventeen cases. In these cases various symptoms of vegetative nervous-system origin were apparent, and in about half of these cases dilatation of the third ventricle could be esen.

Cerebral Palsy with Decortication Rigidity. Dr. Ito and Dr. T. Takahashi (Tokyo) reported their clinical findings in twelve patients with decortication rigidity. These findings included severe rigidity of the limbs (in some cases), moderate spastic rigidity of the joints, tonic neck and righting reflexes, and stereotyped synergies of the upper and lower extremities caused by rotation of the head.

Experimental Study of Intra-articular Temperature in Joints Fixed in Bent Positions. Dr. Y. Kameda and Dr. I. Chin (Tokyo) described experimental studies on rabbits in which it had been found that the intra-articular temperature of a joint fixed in a bent position in a cast was always higher than that of a joint not so fixed. The temperatures were measured by a thermocouple.

Influence of Adductor Dysfunction on Anatomical Changes in the Hip Joint. Dr. K. Mizutani and Dr. T. Hasue (Tokyo) reported experimental studies on rabbits in which it had been found that when the adductor is divided, the ipsilateral femur remains abducted, the length of the lower limb remains unchanged, the head of the femur tends to become flat, and the neck-shaft angle decreases. It had also been found that there is slight retrotorsion of the head and that the margin of the acetabular roof becomes enlarged. Histological study had revealed swelling of the cartilage cells of the femoral head.

Endemic Study on Spinal Poliomyelitis in the Hachinoe District in Aomori Prefecture. Dr. E. Shiokawa (Hirosaki).

Lambrinudi's Method of Foot Stabilization. Dr. K. Shima (Sapporo) and his co-workers reported the results obtained by this method in the treatment of spastic, poliomyelitic, and congenital club-foot. The criteria used to judge the results were those of Patterson. The author concluded that Lambrinudi's method is not suitable for children under ten only because in these children the posterior process of the talus is still immature. In cases of flail-foot this method by itself is not adequate to prevent instability of the ankle joint. The authors concluded that Lambrinudi's method should be modified by the use of staples and bone-chip grafts.

Strobophotography in Basographic Recording. Dr. S. Iino (Sendai) and his co-workers described their latest improvements in an apparatus designed to provide four-dimensional records of the movements occurring at different points in the body during the different phases of walking. The apparatus has cylindrical lenses which show, by separate vectors, the vertical and horizontal motions. It also contains a device for recording the precise time at which the foot makes contact with or pushes off from the floor. By thus making it possible to obtain four-dimensionally coordinated basograms, the authors have succeeded in providing a concrete foundation for the study of normal walking.

Experimental Study of the Influence of Local Stimulation on Longitudinal Bone Growth in Paralyzed Lower Extremities. Dr. S. Kanai (Noboribetsu) described the results of experiments in which local stimulation was applied to the tibiae of rabbits from which the sciatic nerve had been excised. Local stimulation was obtained by the insertion of ivory pegs, alginic-acid pegs, or cattle-bone pegs in the lower third of the tibia. In the controls the sciatic nerve was cut, but no stimulation was applied. Following the insertion of ivory pegs there was an average overgrowth in the tibia of 1.29 per cent. Following use of alginic-acid pegs, the average overgrowth was 1.77 per cent, and following use of cattle-bone pegs, it was 2.6

per cent. In the control animals there was temporary overgrowth of the tibia, lasting until the epiphyseal cartilage began to close, but three months later there was an average shortening of 2.4 per cent.

Anatomical Study of the Human Hip Joint in the Fetal Stage. Dr. S. Kosuge and Dr. H. Murakami (Nagoya) reported their findings in eleven foetuses from five to ten months old.

Pathogenesis of Congenital Dislocation of the Hip Joint. Dr. K. Fujimoto (Sendai) and his co-workers reported the findings of pathohistological examinations of (1) a female foetus eight months old with subluxation of the left hip, (2) a boy fifteen months old with subluxation of the left hip, and (3) a girl two years and six months old with bilateral dislocation.

External Causative Factors in Congenital Dislocation of the Hip. Dr. H. Imada and Dr. K. Tanaka (Sendai) presented evidence that the incidence of congenital dislocation of the hip in undernourished infants is twice that in normal infants.

The Problem of Anteversion in Congenital Dislocation of the Hip. Dr. S. Morita, Dr. T. Onomura, and Dr. K. Asada (Kyoto) presented statistical evidence that spontaneous correction of anteversion cannot be expected in cases in which more than two years have passed since closed reduction was done. They felt that in such cases rotation osteotomy should be carried out more often than it has been in the past.

Studies on the Mechanism of Trendelenburg's Phenomenon in Congenital Dislocation of the Hip. Dr. S. Wataya, Dr. M. Ishizawa, Dr. K. Mizui, Dr. Y. Hata, and Dr. S. Yuki (Osaka) described their research on the mechanism of Trendelenburg's phenomenon. They reported (1) that changes in muscle power occurring in association with changes in the direction of pull of the adductors had been observed, (2) that electromyographic evidence of changes in the adductors had been obtained when the hip joint was loaded and unloaded, and (3) that arthrography revealed symptoms in the capsule of the hip joint. They concluded that the presence of changes in the adductors is not sufficient to explain the nature of Trendelenburg's phenomenon and suggested that the existence of a new force in the pubo-capsular-ligament portion of the joint capsule is a reasonable explanation.

Treatment of Congenital Dislocation of the Hip at the Department of Orthopaedic Surgery in Fukui Red Cross Hospital. Dr. Y. Kirita and Dr. F. Osada (Fukui) reported their results in a series of 300 cases of congenital dislocation of the hip. Conservative as well as operative treatment had been given, and follow-up had been maintained for three years in each case.

End Results of Conservative Treatment of Congenital Dislocation of the Hip. Dr. F. Ueda (Nagoya) and his co-workers reported the end results obtained by various methods of conservative treatment in eighty-eight cases. The criteria of Lindemann were used to classify the results.

Closed Reduction of Congenital Dislocation of the Hip. Dr. N. Takagishi, Dr. K. Iwagiri, Dr. H. Yoshii, and Dr. H. Tahira (Fukuoka) reported the end results obtained by closed reduction in 2,300 cases of congenital dislocation of the hip. They emphasized the importance of early treatment.

Methods of Treatment of Congenital Dislocation of the Hip. Dr. I. Miki, Dr. H. Miyano, Dr. A. Shimizu, Dr. S. Mizuno, and Dr. M. Kikuchi (Tokyo) discussed the problem of treatment in both the hereditary and exogenous type of congenital dislocation of the hip.

Treatment of Congenital Dislocations of the Hip by a Removable Fixation Apparatus. Dr. Y. Aihara, Dr. H. Murata, and Dr. H. Hashimoto (Osaka) reported their results in 167 cases in which removable celluloid splints had been applied following closed reduction.

"Abduction Diaper" Treatment for Congenital Dislocation of the Hip. Dr. B. Kawamura and Dr. T. Utsumi (Sapporo) reported three-year follow-up studies of 357 patients with hip abnormalities treated by the so-called "abduction diaper" method. They concluded that this treatment is appropriate only in cases of hip dysplasia and should not be used in cases of true dislocation or subluxation.

Diagnosis of Congenital Dislocation of the Hip by Arthrography. Dr. S. Sumiyoshi and Dr. M. Yoshizumi (Nara) reported the results of using lateral arthrograms in conjunction with anteroposterior roentgenograms as a means of obtaining diagnoses.

Centripetal Tendency of the Femoral Head after Reduction. Dr. S. Kanai and Dr. A. Yama-

GUCHI (Utsunomiya) pointed out that the femoral head tends to move centrally after reduction and stressed the importance of this factor in the prognosis.

Experimental Studies on Deformity of the Femoral Head after Reduction. DR. M. KIKUNO, DR. A. HARA, DR. H. NOMURA, and DR. Y. ABE (Tokyo).

Capsular Athroplasty for Congenital Dislocation of the Hip. DR. K. HACHIYA (Nagoya) had used Colonna's capsular arthroplasty to treat twenty-three patients with congenital dislocation of the hip since 1954. He reported his results.

A Method of Obtaining Open Reduction in the Older Child with Congenital Dislocation of the Hip. DR. A. NISHIO and DR. H. SHINGU (Tottori) described the method of reduction which they had devised for use in the older child. In this method the acetabulum is separated from the pelvis without removal of the articular capsule and is then reattached to the pelvis in a better position.

Colonna's Capsular Arthroplasty for Congenital Dislocation of the Hip. DR. S. MIZUNO, DR. T. KINOSHITA, DR. H. ARIMA, DR. S. OOMURA, and DR. M. KAIBARA (Osaka) had treated 105 joints in eighty-five patients by Colonna's capsular arthroplasty. They had extended the upper age limit to beyond ten years, an excellent result having been obtained in a patient twenty-eight years of age. Many difficulties had been met in other older patients, however, including contracture, excessive size of the femoral head, and deficiency in capsular material.

Arthroplasty for Severe Congenital Dislocation of the Hip. DR. G. SHIMIZU, DR. K. SHICHIKAWA, DR. K. MASUHARA, DR. K. WATANABE, and DR. K. NAITO (Osaka) reported a series of 128 hips in 116 patients treated since 1952. In sixty-six hips, acetabuloplasty had been performed, the acetabulum being remodeled without alteration of the femoral head. In thirty hips, arthroplasty had been performed, both the acetabulum and femoral head being remodeled; in thirty-two hips Colonna's capsular arthroplasty had been performed.

Changes in the Ulna in Rachitic Rabbits Following Resection of the Radius. DR. A. MIYAZAKI and DR. MATSUMOTO (Kagoshima) reported that the first change seen after resection of the radius was lowering of the vitality of the bone cells resulting in necrosis. Resorption of the necrotic tissue ensued, followed by the development of osteoid and cartilaginous callus.

Industrial Accidents and Their Compensation. DR. M. TAKAHASHI, president of Tokyo Rosai Hospital, presented statistical studies of industrial injuries and their compensation.

Vertebral Injuries. DR. F. WAKAMATSU (Mimai) presented a statistical study of 6,982 cases of vertebral injury seen in Hokkaido.

Fracture of the Ankle Caused by Industrial Accidents. DR. O. TAKAHASHI (Yokohama) presented a statistical study of the findings in fifty-nine patients with fracture of the ankle. He proposed a new standard of insurance compensation for industrial casualties.

Early Operative Exploration for Spinal-Cord Injuries. DR. I. IMOTO, DR. S. WADA, DR. T. YUBA, and DR. N. ICHIOKA (Osaka) pointed out the importance of early exposure of the dilated portion of the spinal cord and of removal of any laminar or other bony compression.

Tendon Repair in Surgery of the Hand. DR. T. MIYAMOTO, DR. N. ITO, DR. T. YAGORA, and DR. A. IWATSU (Osaka) reported their experiences in fifty-six cases in which tendon repair had been done by Bunnell's technique.

Coal Miner's Elbow Caused by Use of the Compressed-Air Drill. DR. Y. MATSUDA and DR. S. FUJITA presented a study of the elbow joints of coal miners who had used a compressed-air drill for over ten years. They concluded that many of these miners had some form of traumatic arthritis.

Physiological Instability of Joints. DR. M. FUJII and DR. A. KOBAYASHI (Osaka) presented their observations concerning the range of motion in various joints. They reported that the range alters gradually but steadily as the individual grows older. For example, in a child six years old the normal range of lateral instability in the interphalangeal joint is 11 degrees, whereas in the adult it is about 5 to 6 degrees.

Studies on the Origin of Spondylosis Deformans. DR. I. TOCHINAI, DR. H. DEBUCHI, DR. A. SASE,

Dr. K. Tokita, Dr. Y. Ariake, Dr. G. Chiba, and Dr. K. Shirato (Morioka) reported the results of their experimental study of the origin of spondylosis deformans. They had found that compression fractures can cause this condition.

Results of Osteoplastic Partial Laminectomy for Lumbar-Disc Protrusion. Dr. Y. Kirita, Dr. H. Oishi, and Dr. Y. Tsuchiya (Kyoto) reported a series of 115 patients treated by osteoplastic partial laminectomy and facetectomy. All the patients had been followed for at least six months after the operation. In forty-seven of the 115 cases, the final results had been determined by direct observation and in forty-two they had been reported by letter. The remaining twenty-six patients had been lost to follow-up. Seventy-nine of the eighty-nine patients adequately followed had no low-back or sciatic pain at the conclusion of treatment and showed no restriction of spine motion. The remaining ten patients continued to have back discomfort.

Discography. Dr. T. Tomiyama, Dr. K. Ogasawara, Dr. S. Komiyama, Dr. Y. Nakabayashi, Dr. T. Matsuno, Dr. M. Funakoshi, Dr. Y. Komori, and Dr. S. Kozama (Sapporo) reported the findings of discographic examinations of forty-eight discs made between 1952 and 1954. The conditions studied were low-back pain with or without sciatica, osteochondritis of the spine, strain in the lumbar region, spondylolisthesis, and spondylolysis. The contrast medium used was 70 per cent pyracetone. The findings included anterior or posterior protrusion, fissure degeneration, and cicatrization. In eight cases of low-back pain with associated sciatica the symptoms disappeared five to eight weeks after the examination and in no case was there an increase in symptoms.

Pathohistological Study of Abnormal Ligamenta Flavia. Dr. H. Yamashita and Dr. A. Kato (Nagoya) in their pathohistological study of abnormal ligamenta flavia, observed a marked increase in the elastic fibers and a decrease in the collagenous fibers.

Roentgenographic Study of Lumbosacral Mobility in Normal Adults. Dr. H. Hasegawa (Yawata) made a study of the mobility of the lumbosacral spine in twenty-three normal adults. The angles between the vertebrae during motion were measured by various means.

Intervertebral-Joint Changes as a Cause of Low-Back Pain. Dr. S. Kasuga, Dr. K. Hashikura, Dr. K. Ito, Dr. T. Yoneda, and Dr. H. Ishii (Tokyo) had made a study in which roentgenograms showing the small intervertebral joints in fifteen patients were compared with the macroscopic autopsy specimens from the cadavera of the same patients. This study demonstrated that pathological changes in the intervertebral joints may cause low-back pain.

The Diagnostic Value of Roentgenography in Conditions Involving the Cervical Intervertebral Foramina. Dr. T. Nagai and Dr. H. Ogaki (Tokyo) had made oblique roentgenograms of the cervical intervertebral foramina, the angle of the film to the sagittal plane being 50 degrees. They had examined eighty-one patients with cervicobrachial conditions and had found that in those with spondylosis deformans the foramina were narrowed, while in those with cervical-cord tumors the foramina were enlarged.

Electromyography in the Diagnosis of Spinal-Canal Derangements. Dr. M. Sugawara and Dr. S. Nakazawa (Morioka) described their findings in electromyographic studies of seventy-five patients with spinal-canal derangements. On the basis of these findings, they attempted to outline the indications for treatment.

Muscular Action during Walking and Standing in Patients with Paraplegia. Dr. H. Tamura, Dr. A. Kajiwara, Dr. H. Okuno, and Dr. T. Hanaoka (Osaka) had made electromyographic studies of the action of the muscles during walking and standing in patients with paraplegia. They emphasized the importance of training the latissimus dorsi, rectus abdominis, obliquus externus abdominis, and obliquus internus abdominis.

Spinal-Cord Compression. Dr. T. Ito and Dr. Y. Kaneko (Tokyo) had made experimental studies in which the spinal cords of rabbits had been examined histopathologically and electromyographically following compression. When slight compressive forces, either continued or temporary, were applied, anaemia was not severe and there was recovery from the paralysis after the compression had been removed. On the other hand, when strong compressive forces were applied, staining revealed marked decrease in or disappearance of the mitochondria and frequent changes in the neurocytes. The electromyographic studies revealed low-amplitude motor-unit voltage and a decrease in unit or fibrillation voltage. In patients with compression myelitis, fasciculation voltage was apparent before operation but disappeared after operation.

Structure of the Filum Terminale. Dr. K. Tsuchiya (Fukushima) described the structure of the filum terminale as it appears macroscopically and histologically.

The Anatomical Basis of Shoulder Pain. Dr. T. Morotomi, Dr. S. Era, Dr. E. Marita, and Dr. S. Horinaka (Hirosaki) reported that in fifty-nine of 108 cases of shoulder pain, the discomfort seemed to be of myofascial origin, being localized in the intraspinatus muscle. The symptoms on which they had based their diagnosis included local tenderness and the radiation of the pain to the shoulder and upper arm on pressure. The area in which spike discharges were shown in the electromyogram conformed to that in which there was radiation of pain following local injection of 6 per cent saline solution. The results of perception and perspiration tests had been positive.

Studies on the Innervation of Bone Marrow. Dr. B. Takase, Dr. S. Nomura, Dr. S. Yonezawa, and Dr. K. Tsubota (Kanazawa) had made experimental studies of the nervous elements of the blood vessels and parenchyma of the bone marrow. In these studies they had decalcified the tibiae of young mice, impregnated them with silver, and made from them serial sections which they had examined minutely. Their findings included the following. The extrinsic-nerve fibers enter the marrow through the nutrient foramina and then course along the arteries of the marrow, ramifying repeatedly at the bifurcation of the vessels. From these nerve fibers there are branches to the parenchyma which end freely or in nodular swellings among the marrow cells. Some myelinated fibers innervate the venous sinuses and endosteum. The authors also carried out degeneration experiments in order to determine the source of the extrinsic-nerve fibers. They had found that the fibers that course along the arteries of the marrow are mainly sympathetic, probably vasomotor in nature, and that the parenchyma is innervated mainly by the sciatic-nerve fibers but partly by the sympathetic-nerve fibers that course along the femoral artery. The authors concluded that the function of the bone marrow may be controlled by these two nerve elements.

Peripheral-Nerve Fibers in the Sacro-iliac Area. Dr. T. Nakagawa (Tokyo) described the distribution of the nerve fibers innervating the sacro-iliac joint and adjacent parts.

The Amputation Stump in Patients with Leprosy. Dr. T. Kitagawa, Dr. T. Nagata, and Dr. J. Ide (Kumamoto) had made a study of amputation stumps of the lower extremities of lepers in order to devise a more suitable type of prosthesis. In all cases they had found hyperaesthesia or anaesthesia due to neuritis. The eyes and hands of many of the patients were so severely affected that the handling of a prosthesis was difficult; and in 23.5 per cent there were chronic ulcers in the region of the capitulum fibulae. Hardness of the stump muscles (gastrocnemius) was not usual, and most stumps showed little or no sweating, although a few showed abnormal sweating. The temperature of the stump skin was found to be lower than it is in other amputees.

Course of Arthritis During Treatment. Dr. M. Watanabe, Dr. S. Takeda, and Dr. H. Ikeuchi (Tokyo) had attempted to determine the course of arthritic conditions during treatment by studying the changes in (1) the blood sedimentation rate, (2) the synovial fluid, and (3) the synovial membrane. They described their findings following the use of chemotherapy.

Experimental Studies on Hypophysectomized Rats with Traumatic Arthrosis. Dr. K. Fukumoto (Kurume) had produced traumatic arthrosis in the ankle joints of rats upon whom hypophysectomy had previously been done. He had then observed the effects of several different drugs on the pathological changes in these joints.

Results of Synovectomy in Patients with Chronic Hydrarthrosis. Dr. T. Tsuruta, Dr. Y. Yamate, Dr. C. Hara, Dr. K. Nabeshima, and Dr. Y. Komori (Mie) had performed synovectomy upon seventeen joints in six patients with chronic hydrarthrosis. This treatment had been used only in patients in whom long-term medical and physical therapy had failed. The patients had been followed for from three months to three years.

A Method of Synovectomy of the Knee Joint. Dr. M. Mori (Niigata) and his associates presented a technique which they had used since 1954 with satisfactory results.

Influence of Peg-Grafting on Longitudinal Growth in Patients with Legg-Perthes Disease. Dr. K. Sakakida (Tokyo) had treated fifteen patients by this means, the pegs being inserted through the epiphyseal cartilage plate. One and one-half years after the operation there was slight overgrowth, but later the epiphyseal plate closed prematurely and shortening resulted.

Disturbances in the Longitudinal Growth of the Long Bones Due to External Fixation.

DR. S. WASHIYA (Tokyo) had found, clinically and experimentally, that disturbance in the calcification of the epiphyseal cartilage could be detected only after external fixation had been maintained for two months. When fixation was prolonged for over five months, disturbance in the cartilage proliferation could also be seen.

Study of Calcification by Means of Tissue Culture. DR. K. TATEIWA, DR. K. YOSHIZAWA, and DR. A. SHIMIZU (Tokyo) reported the results of their study of the calcification mechanism. They had used the roller-tube method, culturing femoral and tibial tissue from old chick embryos in the presence of various inhibitors.

Study on Bone Protein. DR. H. OKAMOTA (Tokyo) had made biochemical and physiological studies of the soluble protein of the compact substance of bone. He concluded that the paper-electrophoresis reaction of the saline-extract solution generally parallels that of gamma-globulin serum.

Influence of Parotin on the Growth of the Long Bones. DR. H. HONKAWA (Tokyo) had attempted to promote longitudinal growth of the long bones by use of parotin. The results of this experiment had been positive in rabbits but negative in human beings.

Blood Sedimentation Rate in Patients with Bone Fracture. DR. S. TAKANASI (Tokyo) discussed the factors which cause an increase in the blood sedimentation rate in patients with bone fractures. He analyzed statistically the correlation between the blood sedimentation rate and (1) the specific gravity of whole blood or plasma, (2) the hematocrit, (3) the plasma viscosity, and (4) the plasma-protein ratio. Specimens of blood from forty-one patients had been examined, the following findings being observed: (1) there is no correlation between the blood sedimentation rate and the specific gravity of whole blood or the hematocrit; (2) there is no correlation between the blood sedimentation rate and the amount of albumin or gamma-globulin present; (3) the factors which seem to influence the blood sedimentation rate are the specific gravity of the blood plasma, the plasma viscosity, and the amount of fibrinogen, alpha-globulin, and beta-globulin present.

Influence of Minute Blood Vessels on Fracture Healing. DR. S. HAMADA (Yokohama) had studied the effect on fracture healing of increasing minute blood vessels by using purified vaccine and ovarian hormone. He reported that ossification could be completed in about three weeks when the purified vaccine was utilized.

Effect of Various Medicaments on Fracture Healing as Observed with P^{32}. DR. T. KIDO (Kanazawa) reported his results in this field by the use of this technique.

Influence of Iron on Bone. DR. E. WAKAMATSU (Akita) reported the histological effects of iron on bone as observed after its insertion into the tibiae of rabbits.

Statistical Observations on Fractures. DR. N. SHIOTSU, DR. T. OTSUKA, DR. M. NAKAWAKI, DR. S. RIN, DR. S. YAMADA, DR. T. KAGAWA, DR. H. NAKAMURA, DR. T. YAMAGATA, DR. T. YAMAMOTO, and DR. S. OGAI (Shimane) reported their data from Tamatsukuri Hospital.

Treatment of Fractures of the Calcaneus. DR. D. KASHIWAGI, DR. K. NAKANO, DR. H. UMESAKI, DR. U. KITAOKA, and DR. M. TAKATA (Kobe) reported the results obtained by various methods.

Fracture of the Lower Half of the Tibia. DR. M. KAIBARA, DR. K. MAEDA, DR. T. FUJISHITA, DR. S. MATSUO, and DR. T. SHIBATA (Osaka) discussed results in 242 cases of fracture in the lower part of the leg.

End-Result Study of Eighty-Three Meniscectomies. During the past six years, DR. M. UCHIMURA, DR. T. IWANAGA, DR. M. ASANO, DR. M. OTA, and DR. Y. MORISHIMA (Yawata) had treated eighty-three knees in seventy-eight patients by the total removal of the menisci. The end results were investigated in forty-nine knees. Ninety per cent of those were excellent or good, but a slight increase of the changes of arthritis deformans was noted in 34.6 per cent.

Clinical and Anatomical Studies of the Meniscus. Ninety specimens of fetal meniscus were observed histologically and anatomically, and twenty-one specimens of meniscus obtained at autopsy were examined clinically by DR. H. HASHIMOTO, DR. K. GOTO, and DR. T. GOTO (Kumamoto). The authors reported their findings in detail.

Experimental Studies on the Regeneration of Cartilage. Dr. S. Murachi, Dr. H. Shibata, Dr. K. Tsuji, Dr. S. Uga, and Dr. M. Minami (Tokyo) had studied normal cartilage and its regeneration in mature rabbits, using histochemical methods. They concluded that perichondrium is important in the regeneration of rib and ear cartilage. They also reported that the stainability of new-formed cartilage increased progressively with growth.

Calcium Metabolism of Bone as Observed through the Use of Ca^{45}. Dr. I. Hashimoto, Dr. A. Hayashi, Dr. K. Fukuoka, and Dr. H. Tanimukai (Kyoto) studied calcium exchange in bones stored in various solutions (autoserum, serum-Ringer's solution, Ringer's solution, physiological saline, 70 per cent alcohol, 2 per cent chlorcalcium). The results were as follows: (1) ion exchange and recrystallization occurred in two days and about one-half of the Ca^{45} in exchange equilibrium had been absorbed by the stored bones; (2) bones boiled for one hour showed a higher calcium-exchange rate than did fresh bones (the minimum rate was observed in bones boiled for five minutes); (3) in the bones preserved in autoserum and serum-Ringer's solution, ion exchange and recrystallization continued, but not in the other solutions.

Study of Bone Dynamics. Dr. I. Yasuda discussed the dynamics of fracture healing, chiefly that stimulated by mechanical stress and electrical energy, and derived a formula for the energy applied to the bone. It has long been assumed that callus formation occurs only in relation to fractures, but a few years ago Küntscher showed that callus-building is possible through biochemical, thermal, or chemical irritation. This mechanism was called "callus without fracture," and the principle involved has been employed in the treatment of fractures. The author again investigated this phenomenon, using a rabbit femur, and concluded as follows: (1) the callus formation appears when tension or compression is applied to the bone; (2) the quantity of callus is directly proportional to the amount of mechanical energy applied to the bone. It was further assumed that mechanical energy stimulates bone metabolism. Periosteal bone formation is concerned in this increase.

Since the activities of living bone are always accompanied by the production of electricity, the author assumed that the bone tissue where the callus formation occurs is electrically charged. In order to confirm this presumption, Dr. Yasuda performed various experiments using tubular bone, and concluded that the concave side of bone is electrically negative, while the convex side is positive. The author recognized that electricity is produced if mechanical energy is applied to bone, and that "two-phase electric waves" are produced during walking, running, jumping, or other exercises. This phenomenon may be noted not only in living bone, but also in dead, in boiled, or in decalcified bone tissue, and may be related to the deformation of collagenic fibers.

In regard to callus formation, mechanical and electrophysiological investigations were performed and it was noted that forces such as vibration, electricity, and heat produce callus. The mechanical energy is partially changed to electrical energy and irritates the bone tissue. Therefore, the callus is formed. If these assumptions are correct, it must then be possible to produce callus with electricity alone. To test these assumptions, two needle electrodes were inserted through the cortex of a rabbit femur into the bone marrow. A current of one micro-ampere was passed between the electrodes, 1.5 volt batteries being used. After three weeks, callus formation was noted between the electrodes, periosteally and endosteally. This newly formed callus was called "electrical callus." The amount of electrical callus was directly proportional to the magnitude of the electrical current.

Fundamental Studies of Traction Treatment of Fractures. Dr. K. Ikeda (Tokyo) studied experimentally the biological effects of traction on muscles and on bone union. He concluded that these effects were closely related to systemic changes and that an optimum weight should be utilized in order not to harm muscles and blood vessels, cause degenerative changes in all parts of the body, and delay the bone union.

Closed Reduction of Fractures of the Lateral Condyle of the Humerus. Dr. S. Miyagi and Dr. T. Maeda (Kurume) reported that they were successful in effecting closed reduction in twenty cases of fractured lateral condyle of the humerus, even when the fragment was rotated.

Bone Transplantation. Dr. B. Kawamura (Sapporo) reported the results of his study of bone grafts. Out of 303 cases there was successful transplanting of autogenous-bone grafts in 81.8 per cent, deep-frozen bone in 86.3 per cent, and malleable bone chips in 92.9 per cent.

Experimental Studies on Bone Formation. Dr. S. Hattori, Dr. H. Fukuta, Dr. T. Oishi, Dr. N. Kato, Dr. G. Kunimi, Dr. R. Ono, Dr. K. Sakamoto, and Dr. S. Matsumori (Tokushima) had transplanted fresh autogenous fibrocartilaginous callus, articular cartilage, epiphyseal cartilage, cortical bone, cancellous bone, and bone marrow to the anterior chambers of rats' eyes. They reported that they found new-bone formation in each case. Following these experiments, the authors concluded that young connective

tissue with plenty of blood vessels from adjacent host tissues is the most important factor in bone formation.

Study of Bone Induction. Dr. M. Matsubara and Dr. T. Momura (Fukuoka) conducted studies to determine the osteogenetic potencies of various kinds of tissues. They found that the transplantation of periosteum, marrow, or the residual substance of the bladder mucous membrane resulted in marked osteogenesis.

Autoradiographic Study of Phosphorus Metabolism in the Experimental Bone Graft. Dr. Y. Murakawa (Fukuoka) had performed a total of 134 bone-graft procedures. His autoradiographic studies of the phosphorus metabolism of the grafts yielded the following results. The amount of phosphorus around the graft increased after five to seven days, reached a maximum after two to three weeks, and then decreased. The uptake of phosphorus within iliac fragments was apparent in the earliest stage of transplantation. After three weeks absorption and ossification occurred more quickly. The radioactive phosphorus was deposited along the new, growing trabeculae; its deposition did not seem related to the localization of alkaline phosphatase.

Experimental Studies on the Influence of Parathormone on Healing of Bone Grafts were reported by Dr. M. Momota (Kurume).

Amino Acids in the Healing of Bone Lesions. The efficacy of essential amino acids in experimental fracture healing had been investigated by Dr. M. Harada (Wakayama) in white rats weighing about 150 grams. These white rats were fed a basal diet for the first week and a protein-free diet for the next. They were then divided into four groups according to the kind of diet ingested. The findings imply that the metabolism of bone salt was actively carried on at the fracture site in groups with excess leucine, lysine, and tryptophan, and that leucine is more effective in fracture healing than any other amino acid.

Bone and Hormones (Second Report). Changes in bone tissues and endocrine glands were studied in dogs and rats by Dr. M. Nakagawa, Dr. S. Ozaki, Dr. T. Kitaura, and Dr. M. Matsushima (Wakayama), using D.D.D., an adrenocorticolytic agent. This drug atrophies the adrenal cortex, increases insulin sensitivity, and inhibits the production of alloxan diabetes. The results of this study clarified that the effects of D.D.D. on bone tissues and the pituitary body were caused by disturbances in endogenous hormone production.

AMERICAN COLLEGE OF SURGEONS

THE FORUM ON FUNDAMENTAL SURGICAL PROBLEMS

Orthopaedic Section

The Forum on Fundamental Problems relating to orthopaedic surgery of the Forty-Third Clinical Congress of the American College of Surgeons was held in Atlantic City, New Jersey, October 16, 1957. The session was presided over by Dr. Robert Robinson and Dr. Crawford Campbell. Among the formal presentations were the following:

The Local Effect upon Bone, Cartilage, and Joint Tissues of the Polymerization of Methyl Methacrylate *In situ*. Dr. Harry T. Glaser[1], to ascertain the effect of the local polymerization of methyl methacrylate upon bone, cartilage, and joint structures, mixed the liquid and powder forms, and injected them into the knee joints of a group of dogs. Very high temperatures were noted in the area in which the hardening of this material occurred. As a control procedure, the contralateral joints were opened, mechanically sacrificed, and closed. The animals were sacrificed at intervals from the first week to the eighth month, and the affected joints and their controls were studied. There was histological evidence of chondritis, non-infectious osteomyelitis, osteoclasis, new-bone formation, and capsular fibrosis. The changes appeared maximal at about the fifth month, and showed some evidence of subsiding by the eighth month. Despite the reactions noted in the knee joint, the author stated that he has used methyl methacrylate in disc spaces of patients, following the removal of herniated discs without any complications up to the present time in fifteen patients so treated.

[1]Buffalo General Hospital, Buffalo, New York.

Transplantable Osteogenic Sarcoma of the Mouse Exposed to Vitamin-A Intoxication and Vitamin-D Deficiency. DR. EDWIN G. BOVILL, JR.[2] reported that an osteogenic sarcoma of spontaneous origin in the mouse (C3H) from the National Cancer Institute was successfully transplanted through seven successive passages and was observed grossly and microscopically after subjecting the host animals to vitamin-A intoxication and vitamin-D deficiency. Six-week-old animals were used. The diets were normal until transplantation. Administration of vitamin A in excess and the change to a vitamin-D-deficient diet were carried out at the time of transplantation. The animals were sacrificed at four to five weeks and the weight changes recorded. In the vitamin-A-intoxication group, the control animals and tumors weighed slightly more than the treated animals and tumors but the difference was not considered significant. In the vitamin-D-deficient group, the control and treated animals weighed the same. The tumor weights in the vitamin-D-deficient animals were less than those in the control animals. The autonomous nature of the sarcoma was unaffected. The histological appearance of the sarcoma in the treated animals did not differ from that in the control animals. The author concluded that the typical dependence of epiphyseal cartilage on normal amounts of vitamin A and vitamin D is not reflected in the growing cells of this osteogenic sarcoma under the conditions described.

Comparison of the Effects of Cortisone and Nilevar (17-Ethyl-19 Nortestosterone) on the Uptake of Radioactive Sulphur on the Fractured Humerus in the Rat. DR. K. KOWALEWSKI[3] and DR. R. K. LYON stated that in previous reports they were able to demonstrate that fractured humeri of rats showed an increased uptake of S^{35} as compared with the uptake in the intact bones of the same animals. Other studies indicated that their procedure of investigating collagen formation in healing fractures with S^{35} may be utilized for the study of the catabolic and anabolic effects of various substances on bone. It was reported that an attempt was made to calculate the effect of cortisone and nilevar on the formation of callus. The uptake of S^{35}, which the authors felt was related to the synthesis of chondroitin sulphate in collagen tissue, was utilized as the method of evaluating the effect of these substances. One group of rats received cortisone and one received nilevar; a third group, given both substances simultaneously, was also studied. Rats were sacrificed three weeks after the fracture of the humerus and the S^{35}-uptake study was done. The ratio, F/I, of the uptake of S^{35} by the fractured bone (F) to the uptake of S^{35} by the corresponding intact bone (I) was calculated. The uptake of S^{35} in fractured bone was significantly inhibited by cortisone and stimulated by nilevar. The inhibitory effect of cortisone was not found to be significant when nilevar was given simultaneously to the rats. Autoradiographs were shown to illustrate the effects noted.

The Effect of Total Body Irradiation on Bone Transplants in Parabiotic Animals. DR. W. F. ENNEKING[4], DR. AVRUM GRATCH, and DR. HEBER ETHRIDGE had demonstrated previously that large fresh homogenous-bone transplants evoke an inflammatory response in the recipient animals. This response was accelerated by the use of the second-set transplant technique and was redemonstrated by the exchange of similar transplants between members of a parabiotic union. The authors reported the results of the histological investigation of large fresh homogenous-bone transplants exchanged between members of an irradiated parabiotic union. One member of the union received total body irradiation prior to surgical parabiosis. Weekly doses of total body irradiation were administered to this member while the non-irradiated member of the union was shielded. Transplants were exchanged after the twenty-first day following parabiosis. Specimens were obtained for histological study at intervals following transplantation. Three hundred and seventy-three unions were prepared and 102 specimens obtained for study. The surviving members of the unions from these experiments were maintained for six months and then separated. In this procedure, closure was accomplished in one animal with skin of its partner creating large homogenous pedicle-flap skin transplants.

The authors noted that, in those randomly selected parabiotic rats which had received large amounts of total body irradiation, the inflammatory reaction noted about the transplants was absent. Even in the non-irradiated rat of a parabiotic pair whose partner had received the total body irradiation as noted, the reaction was markedly diminished about the homogenous transplant.

A Study of Back Pain: The Use of Progressive Resistive Exercises as a Primary Mode of Treatment. DR. CARROLL B. LARSON[5] and DR. MARVIN DUBANSKY reported a study involving sixty male students, ranging in age from seventeen to fifty years, who were referred by the Student Health Department. The subjects were given a complete physical examination, including roentgenographic studies. All subjects

[2]Stanford University School of Medicine, San Francisco, California.
[3]McEachern Laboratory, Department of Surgery, University of Alberta Faculty of Medicine, Edmonton, Alberta, Canada.
[4]Department of Surgery, Division of Orthopaedics, University of Mississippi Medical Center, Jackson, Mississippi.
[5]Department of Orthopaedic Surgery, University Hospitals, State University of Iowa College of Medicine, Iowa City, Iowa.

who had a history of chronic or recurrent backache, or both, were referred to the Department of Physical Education for a series of resistive abdominal and back exercises. The heavy-resistance exercises included trunk extension, leg extension, and trunk flexion. They were selected for the purpose of strengthening the abdominal and back muscles in order that (1) the skeletal structure would be stabilized and (2) the subject would be able to exert greater force without risk of damaging his back. Each subject was instructed to report to the therapist three times a week for exercise. The therapist recorded the amount of weight and the number of lifts performed each session, and kept a record of the comments made by the subject in respect to the condition of his back. At the conclusion of the experiment the subject was given a second medical examination and a final test to measure the strength of his abdominal and back muscles. If the subject's back pain persisted, his condition was recorded as *no change*. If he experienced considerable relief, and had infrequent recurrences, he was given a rating of *better*. When the subject became free of all symptoms of back pain, he was considered *relieved*. It was reported that forty-two subjects were relieved, fifteen were better, and one did not improve. The greater gain in per cent of strength, based on the initial measurements for the one-lift maximums, was recorded for the abdominal muscles, indicating that most subjects had weak abdominal muscles compared with their back muscles.

The authors tabulated two back-abdominal strength ratios for each subject, using the original and final measurements. They stated that these results indicated that the subject who had a back-abdominal-strength ratio higher than three to one needs to concentrate on abdominal exercises, while the subject with a ratio of two to one or lower needs to concentrate on back exercises. In either case, the authors stated that participation in a program of heavy-resistance exercises will tend to bring about the proper balance. Since the majority of the subjects in this study were relieved of their back pains by participating in the heavy-resistance exercises, the authors felt that probably a back-abdominal-strength ratio of three to one may be used as a criterion to determine the degree of development to strive for in exercising subjects with back syndromes.

Experimental Epiphysiolysis in Rats. Dr. J. Hillman[6], Dr. William Hunter, and Mr. John Barrow used a laboratory method devised by Harris to measure the shearing force required to separate the epiphysis from the diaphysis of the rat tibia. The rats were divided into three categories: normal animals, estrogen-treated animals, and into a group in which the added factor of injury was introduced by performing operative lysis of the proximal tibial epiphysis nine days prior to sacrifice. Each of these groups was evaluated by the use of appropriate control animals.

The authors said the results indicated that estrogen therapy increased the required shearing force, that nine days following lysis the healing area had more stability than the uninjured epiphysis, and that the most resistant preparations were in animals subjected to lysis in addition to estrogen therapy. The authors felt that the epiphyseal zone of the rat tibia may serve as a biological-test medium for further study of the effect of certain steroid compounds known to influence growth.

The Effect of the Addition of Plaster of Paris to Autogenous and Homogenous Bone Grafts in Dogs. Dr. L. F. Peltier[7], and Dr. Duane Orn reported an experiment in which the purpose was to evaluate the use of plaster of Paris as an "extender" in bone-grafting. Diaphyseal defects four to five centimeters long were produced in dogs by resecting the shaft of the radius and its periosteal covering. The defects were reconstructed with (1) autogenous-bone grafts; (2) autogenous-bone grafts and an equal amount of plaster of Paris; (3) homogenous-bone grafts; and (4) homogenous-bone grafts and an equal amount of plaster of Paris. According to the authors, no evidence could be found that the presence of plaster of Paris affected bone regeneration adversely in any of the thirty-three dogs so tested. The addition of the plaster to autogenous-bone grafts did not appear to have any effect upon the end result. No foreign-body reaction was noted about the areas of plaster insertion. It was found that the addition of plaster to homogenous-bone grafts resulted in an increase in the number of dogs showing full regeneration of the bone defects. A clinical case was presented in which the patient had a large bone defect. Pellets of sterilized plaster of Paris had been placed in and about the bone graft at the time of reconstruction. Follow-up roentgenograms showed healing of the fracture and defect.

Bone Transplantation in Dogs Using Beta-Propiolactone as a Sterilizing Agent. Dr. D. A. Baird[8], Dr. G. H. Ryan, and Dr. C. C. Ferguson reported that approximately 100 autogenous and homogenous bone grafts were inserted in radial and tibial defects in thirty dogs. Some grafts were sterilized with beta-propiolactone and some were autoclaved. Untreated sterile grafts were inserted as controls. The fate of these grafts was assessed at regular intervals by roentgenographic, gross, and histological examination. The results revealed that there is variability in the acceptance of homogenous grafts by the host but the

[6]Division of Orthopaedic Surgery, Department of Surgery, Vanderbilt University School of Medicine, and University Hospital, Nashville, Tennessee.
[7]Department of Surgery, University of Kansas Medical Center, Kansas City, Kansas.
[8]Department of Surgery, University of Manitoba Faculty of Medicine, Winnepeg, Manitoba, Canada.

large majority is eventually well incorporated. After treatment with beta-propiolactone, the authors stated that there was no demonstrable alteration in the healing propensity of either the autogenous or homogenous grafts. They felt that bacteriological studies reaffirmed its effectiveness as a sterilizing agent.

The authors concluded that the autogenous graft is undoubtedly the graft of choice, but, in addition, that beta-propiolactone sterilization of homologous bone has been shown to be a satisfactory method of establishing a reliable homologous-bone bank.

Spectrophotometric Curves of the Urine in Patients Who Undergo Operations on the Bones and Joints. DR. J. A. NICHOLAS[9], DR. P. D. WILSON, MR. FRANCO FIORESE, and DR. C. J. UMBERGER noted predictable changes in the spectrophotometric study of the urine of these patients. A strongly absorbing substance appeared at 270 micra, followed by a gradual return of the spectra to a preoperative pattern as the patient recovered. Carefully controlled studies were carried out on thirteen patients who were undergoing trauma or surgery on the bones and joints and on twenty control patients. It was noted that with the appearance of this absorption band there was a disappearance of hippuric acid. The possibility that the substance accounting for the band at 270 micra might be linked to the metabolism of hippuric acid was entertained.

[9]Margaret Caspary Laboratory for Research, Hospital for Special Surgery, Cornell University Medical School, New York, N. Y.

DISCUSSION

RADIATION STERILIZATION OF BONE TRANSPLANTS

(Continued from page 203)

With respect to the freeze-dry method itself, it is strongly recommended that descriptions of the method be precise. For example, bone thermocouple studies would be helpful in determining whether or not the bone thawed during drying. If significant case-hardening occurs, it would seriously interfere with saline reconstitution of the graft and an inferior graft would result. If suitable thermocouples are lacking, it is important to specify condenser temperatures and vacuum readings during the freeze-dry cycle. It is our impression that to have a graft which will withstand long-term storage, we should approximate a residual moisture of from 2 to 3 per cent.

Our group has had no experience with cobalt-60 as an irradiation source for bone sterilization, but we have evaluated certain aspects of the cathode ray. Turner and associates showed that freeze-dried cortical bone of dogs treated with two million roentgen equivalent physicals (cathode ray) evidenced mild but notable delay in graft revascularization. Six million roentgen equivalent physicals resulted in gross revascularization delay. Handbook 47 of the National Bureau of Standards states that for the purpose of calculation the relative biological efficiency of a given radiation is the same.

Bassett, at Columbia-Presbyterian Hospital, has applied the cathode-ray sterilization principle to human frozen homogenous bone treated at two million roentgen equivalent physicals. Clinically, the short-term results are satisfactory.

It would seem that the authors' use of four million roentgen equivalent physicals of the gamma ray might lead to graft damage. A possibility might be to carefully select the cadaveric donors and use two million roentgen equivalent physicals of the gamma ray for sterilization of the usual operating room contaminants. It was properly emphasized that Dr. DeVries' presentation is a preliminary report on short-term follow-ups. Notable was the figure of seventy-six spine fusions out of 104 operations. In our clinical research project, we found the long-term spine fusion results with reference to the graft-host union extremely difficult if not impossible to evaluate without operative inspection. These results too were unsatisfactory statistically.

I should like to emphasize that the differences in methods and the variety of experimental approaches represent the troubles that beset our group for the past five years. It may be that the long-term clinical results will verify the authors' early clinical impression.

To be able to sterilize bone and not worsen the inherent disadvantages of a homogenous-bone graft would be a noteworthy development. We shall look forward to publication of the long-term clinical results of freeze-dried homogenous-bone grafts sterilized by irradiation from cobalt-60.

AMERICAN MEDICAL ASSOCIATION
SECTION ON ORTHOPAEDIC SURGERY

As Prepared by H. Herman Young, M.D., Rochester, Minnesota

The Annual Meeting of the Section on Orthopaedic Surgery, the American Medical Association, was held in New York, N. Y., June 5, 6, and 7, 1957, under the chairmanship of Dr. Edward L. Compere, Chicago, Illinois. The program was devoted almost entirely to traumatic surgery. Résumés of the papers presented follow.

Closed Reduction of Common Shoulder and Elbow Dislocations without Anaesthesia. Lt. Col. Robert W. Parvin [1] reported that since June 1954, he had treated twenty-eight dislocations of the shoulder and twenty dislocations of the elbow at the United States Army Hospital at West Point. Reduction was obtained without anaesthesia in each case and he stated that he had not used anaesthesia during the reduction of a shoulder dislocation since 1951. His patients, with few exceptions, were young men, and they were usually treated within an hour after injury. Of the twenty-eight patients who had dislocation of the shoulder, two had associated fracture of the greater tubercle. Apparently none of the twenty patients having dislocation of the elbow had associated fractures.

Shoulders were reduced in most cases by a modified Milch prone-abduction traction technique. In a few cases, the Böhler method of self-reduction was used and patients with recurrent dislocations who refused operation were taught this method of reduction. Bennett's supine technique of traction in abduction was used in two cases, but this method was not felt to be so atraumatic as the other two methods. Since the actual manipulation time may be rather long, these methods are not suitable for the impatient "quick-pull" artist. The advantages are the avoidance of general anaesthesia and the lessening of the painful interval between dislocation and reduction. The average period of immobilization was three weeks.

The dislocated elbow was reduced by the prone traction-manipulation method with invariable success. Again, gentle prolonged traction was emphasized since forcible traction resulted in spasm and failure. Immobilization for three weeks was advocated for elbow dislocations. Full motion may be expected to be regained in from six weeks to six months. It was pointed out that reduction of dislocated elbows by this method is so gentle that frequently the surgeon is not certain when reduction occurs. Rarely did a patient in this series require anaesthesia in order for a fresh fracture of the shoulder or the elbow to be satisfactorily reduced.

Lt. Col. Parvin's presentation was followed by a paper on the use of local anaesthesia in the treatment of fractures and dislocations. The authors pointed out the economic advantages of local anaesthesia over the use of general anaesthesia, just as Lt. Col. Parvin pointed out the desirability of reducing dislocations of the shoulder and elbow without anaesthesia. They advocated the use of lidocaine which they consider a safe local anaesthetic agent.

The Use of Local Anaesthesia in the Treatment of Fractures and Dislocations. Dr. R. H. Ramsey [2] and Dr. Herbert E. Pedersen [3] reported on the care of 169 patients with fractures, dislocations, and epiphyseal separations treated by means of closed reduction and local anaesthesia. Five "pin-point" open fractures included in the group were treated in the same way except for the use of antibiotics. Two-thirds of the fractures involved one or both bones of the forearm in children or adults; 40 per cent of the patients treated were less than fifteen years of age. No more than ten cubic centimeters of anaesthetic agent was used in any case, and less than this amount was used in the majority. A 1 per cent solution of lidocaine without adrenalin was advised for children and a 2 per cent solution for adults. The authors consider local anaesthesia excellent, economically sound, and safe for use in the treatment of many fractures in both adults and children. The advantages of local anaesthesia which they emphasized were: (1) greater margin of safety, (2) elimination of hospitalization, and (3) active cooperation of the patient in maintaining proper position while external fixation is applied. They thought that the newer local anaesthetic agents were just as effective as general anaesthesia.

Intramedullary Pull-Out-Wire Fixation in Surgery of the Hand. Dr. Lee J. Cordrey [4] pointed out the following advantages of Kirschner wire fixation of bone when stabilization is necessary: (1) early mobilization of the uninjured parts can be established with maintenance of function and without loss of position; (2) application of an adequate pressure dressing is possible following this type of fixation and thus prevents formation of hematomata and oedema; and (3) following extensive trauma, maximal stability of

[1] 18 Wilson Road, West Point, New York.
[2] 861 Monroe Boulevard, Dearborn, Michigan.
[3] 861 Monroe Boulevard, Dearborn, Michigan.
[4] 2073 Abington Road, Cleveland 6, Ohio.

the injured parts promotes healing of soft tissue and permits early mobilization of the hand. The author reported that transarticular placement of the pin had not resulted in ankylosis or limited motion when the cartilaginous surfaces of the joint were intact. He felt that postoperative care of the hand was minimized both for patients and physician and permitted earlier return to full function without loss of desired results.

Fractures of the Elbow in Children: A Review of 300 Cases. Dr. Donald J. Maylahn [5] and Dr. John J. Fahey [6] analyzed the end results in 300 consecutive cases of fracture about the elbow in children from the standpoint of frequency of occurrence of each type, incidence of nerve and vascular complications, and residual deformity. General principles of open and closed management were stressed with special emphasis being placed on nerve injuries, their diagnosis, treatment, and prognosis; also stressed was the prevention of complications in the management of the severely displaced supracondylar fracture. In cases of complete displacement of supracondylar fractures the inadvisability of manipulation was emphasized (although not agreed upon by several of the discussors), and treatment with skeletal traction was recommended. It was emphasized that manipulation and remanipulation not only might add to an already evident nerve injury but also might be the cause of a nerve injury. Although in certain cases these procedures may relieve circulatory embarrassment, too often they complicated the vascular problem so that it became necessary to discontinue immobilization in order to reduce the degree of flexion so that circulation to the extremity would be improved. It was felt by the authors that manipulation and remanipulation could in themselves be the cause of Volkmann's ischaemic contracture. No case of Volkmann's contracture was encountered in this series.

It was the feeling of the authors that skeletal traction should be used primarily in all patients with moderate or severe displacement and those with severe swelling and circulatory and nerve embarrassment, and not as a preliminary method to manipulation or after manipulation fails.

In their series, 60 per cent of all fractures above the elbow were of the supracondylar type. There was little if any displacement in approximately 50 per cent of these patients and treatment by cast immobilization gave excellent results. Screw traction was employed initially in 32 per cent of the last forty-one patients with marked displacement, twenty-seven of whom had complete displacement without bone contact. Of the fractures about the elbow, 12 per cent were fractures of the lateral epicondyle. Of these thirty-four fractures, twenty were treated by closed methods and fourteen by open reduction.

Nine per cent of the fractures about the elbow were of the medial epicondyle. Fifty-four per cent of these were associated with dislocations of the elbow and 15 per cent were incarcerated within the joint. In the three patients treated for incarceration, the fragment was excised and in one patient it was re-attached. In the authors' opinion, early exploration is unnecessary if peripheral nerves are injured since spontaneous recovery is the rule. They believed that exploration was indicated only after expected recovery was overdue.

Not all of the discussors felt that such a delay in nerve exploration was a valid conclusion, but they agreed that the authors presented an excellent series of cases.

Treatment of Fractures of the Neck of the Femur with Intramedullary Stem Prostheses. Dr. A. A. Savastano [7], Dr. L. A. Sage [8], and Dr. V. Zecchino [9] reported that about 25 per cent of their patients having fractures of the femoral neck were treated by primary insertion of a prosthesis. Forty-five patients, whose average age was seventy-eight years, were well satisfied with the results. Operation was usually performed six days after the injury and weight-bearing was allowed thirteen days after operation; the hospitalization period was approximately thirty-eight days. On follow-up examination most of their patients stated that they had no pain, and about 40 per cent had an excellent range of motion. Another 40 per cent had satisfactory range of hip motion, while the remainder had only a fair or average range. They reported the following complications: one patient with transient drop-foot, one with backache, one with transient loss of balance, and three with decubitus ulcers which eventually healed. There were no dislocations of the prostheses in the series, although five of the ambulatory patients died from cardiorespiratory disease four to fourteen months after operation. The average follow-up was approximately eighteen months.

It was emphasized fully by the authors that hip-nailing is much more desirable and gives a better result than use of a prosthesis; however, treatment with the prosthesis may be selected for patients who are feeble and fragile but who presumably could walk again if given the proper support in the hip. The procedure also was selected for irreducible fractures in the elderly patient. The advantages claimed for this method are early ambulation, reduced hospitalization or periods in convalescent homes, facilitation of nursing care, the avoidance of secondary reconstructive operations, and a reduction in cost to the patient.

The authors emphasized that although a hip-nailing operation is more desirable and gives a better result in most cases it does carry a calculated risk of non-union and aseptic necrosis. Use of the femoral-head

[5] 1791 West Howard Street, Chicago 26, Illinois.
[6] 1791 West Howard Street, Chicago 26, Illinois.
[7] 205 Waterman Street, Providence 6, Rhode Island.
[8] 122 Waterman Street, Providence 6, Rhode Island.
[9] 199 Thayer Street, Providence 6, Rhode Island.

prosthesis in fresh fractures, when indicated, may reduce the incidence of uraemia, hypostatic pneumonia, and death. It was stressed that the requisites and indications for such a method of treatment are that the patient should be feeble, fragile, and elderly with a fracture high in the femoral neck preferably of the displaced subcapital type. The approach of the authors was conservative; they emphasized that this was not a method of choice in the treatment of the average fracture of the femoral neck.

Ski Injury. Dr. Freeman D. Fowler[10] said that the liability of skiers to injuries of the extremities is not news to the traumatic surgeon, but that the types of injuries encountered in skiers are not commonly seen in the usual practice. The momentum of the skier times the length of the ski exerts a terrific twisting force on the extremities, resulting in a drastic injury. The author discussed the various injuries seen, and reported on the methods that he used in treatment of all types of injuries to the extremities. All procedures were carried out in his office in a small mountain town forty miles away from a hospital with the assistance of his wife as office nurse.

Sundry injuries were encountered, including dislocation of the shoulder and elbow, puncturing and perforating wounds of various parts of the body from ski poles, lacerations of the lower extremities by the ski edges, compression fracture of the spinal column, fracture and dislocation of the ankle and tibia, ruptures of the tendo achillis, fracture of the knee and femur, and ligamentous tears around the knee joint. It was shown what can be learned and done in the emergency handling of casualties with only minimal available facilities. As the author stated, "It was work that had to be done."

The Occult Fractures. Dr. Norman J. Rosenberg[11] and Dr. Rudolph S. Reich[12] pointed out that the presence of occult or unrecognized fractures has been acknowledged since the inception of roentgenographic diagnosis. This acknowledgement, rather than improving the recognition and treatment of undisplaced fractures, seems to have afforded certain security to the physician who receives a negative report from the roentgenologist. The report of a negative roentgenogram only gives a false sense of security and the authors pointed out that the responsibility for diagnosis lies with the clinician. A roentgenogram should be considered only as an aid to diagnosis.

An occult fracture is one that gives clinical signs of its presence, yet it cannot be demonstrated with a roentgenographic examination until reparative changes have occurred. As a result of the delayed roentgenographic findings, many occult fractures still remain untreated and are the cause of pain, anxiety, disabilty, and considerable expense to the patient. Both roentgenologists, by improving their technique and angles of exposure, and physicians who are aware of the occult fracture, are helping to solve the problem.

The authors pointed out that in children occult fractures occur at the epiphysis or as greenstick fractures of long bones. Whenever an epiphysis is the site of a suspected injury, and in children when fracture of an extremity is suspected, a roentgenogram of the opposite extremity may aid in the diagnosis. Spiral fractures of the tibia with an intact fibula are often occult, but inability to bear weight, localized tenderness, and swelling often lead to the diagnosis. Fractures of the carpal navicular are notorious for being occult, and in a patient suspected of having a sprain but whose symptoms persist, roentgenographic examination ten days to two weeks after the injury may reveal the exact cause for the protracted disability as a fracture of this bone.

The authors pointed out that fractures of the head and neck of the radius are among the commonest of the unrecognized fractures. They result from a fall on an outstretched arm, and this history in the presence of painful limitation of elbow motion, point tenderness, and swelling may be sufficient evidence to make the diagnosis even in the presence of negative roentgenographic evidence. The conclusions of the authors were that roentgenograms often fail to demonstrate non-displaced fractures and that the diagnosis is a clinical one. One should suspect an occult fracture when there is painful limitation of motion, point tenderness, and swelling, often with ecchymosis and history of an injury. Occult fractures, they felt, should be diagnosed and treated positively.

Moderately Severe Whiplash Injuries of the Cervical Spine and Their Roentgenographic Diagnosis. Dr. Martin S. Abel[13] presented the most controversial paper of the entire session. It was recognized that the so-called whiplash injury has become commonly known among lawyers and that physicians are trying to solve the problem. The author attempted to reproduce the trauma of the whiplash injury in cadavera. He felt that maximal damage in moderate injuries of this type occurred when force was applied so as to cause hyperflexion or hyperextension in the neck in an oblique direction. Experimentally, the weakest bone links in the spinal column appeared close to the regions of change in flexibility, that is, one or two vertebrae above the cervicothoracic junction and in the uppermost cervical vertebrae. He claimed that his experimental results rather closely resembled those of equivocally traumatized patients. In the experimental

[10] Box 36, Idaho Springs, Colorado.
[11] 10900 Carnegie Avenue, Cleveland 6, Ohio.
[12] 10900 Carnegie Avenue, Cleveland 6, Ohio.
[13] 655 Sutter Street, Suite 202, San Francisco 2, California.

results three types of cervical fractures were produced by unilaterally forced hyperextension and hyperflexion in the cadaver. These were clinically found to occur associated with relatively minor predominant unilateral whiplash injury. The injuries produced by forced hyperextension and hyperflexion were fractures of the isthmus and lamina of one or more of the lower cervical vertebrae or fracture of the transverse processes of the first and second cervical vertebrae and also fractures of the elements of the Luschka joints. Four of twenty-one cadaver necks dissected showed premortem isthmus fractures. The author felt that these fractures were not easily visualized on routine roentgenographic views of the cervical spine. In his experience two additional stereoscopic views were necessary, preferably with direct differential-magnification technique. He used a modified basilar view of the skull centered over the first cervical vertebra for adequate visualization of the first and second cervical vertebrae, and an anteroposterior view at an angle of 30 degrees caudad for accurate visualization of the posterior elements of the lower cervical vertebrae.

The author had a scientific exhibit to substantiate his views, but from the spirited discussion which followed the presentation of the paper, it was apparent that the matter was quite controversial, and that there was much concern about the medicolegal implications raised. The author himself stressed the need for caution and confirmatory follow-up examinations in clinical roentgenographic evaluations. Needless to say, the subject of the whiplash injury has not been sufficiently documented medically and further investigations of the injury are necessary before definite scientific statements regarding it can be established.

Fractures of the Distal Third of the Femur. Dr. Marcus J. Stewart [14] and Dr. Sidney L. Wallace, Jr.[15] reviewed the records of 172 patients with 176 fractures of the distal third of the femur from the files of the Campbell Clinic over a ten-year period. Adequate follow-up studies were obtained for eighty of the 172 patients. The shortest period of follow-up was one year, the longest was fourteen years, the average 3.7 years. The patients were divided into those who received closed treatment and those who had open or surgical treatment. The results were reported and the methods critically evaluated.

Thirty-one of the eighty patients had surgical treatment of some type. One of these underwent immediate amputation due to extensive vascular and nerve damage. In thirty, open reduction with some form of internal fixation was employed. For these thirty, the results were excellent in four, good in seventeen, fair in five, and poor in four. In this group, there were two instances of delayed union and six of non-union. A review of the six cases of non-union showed that the only common denominator was operative intervention.

Forty-nine of the eighty patients were treated by closed methods. The results were excellent in thirteen, good in twenty-seven, fair in seven, and poor in only two. Non-union did not occur in any of these patients. The best results were obtained by the so-called two-pin traction method; that is, skeletal traction applied with a Kirschner wire and spreader loop. The authors recommended the use of one Kirschner wire through the tibia at the level of the tuberosity with fifteen pounds of traction in line with the femur, and that a second Kirschner wire be placed at the level of the proximal pole of the patella or adductor tubercle with about three pounds of traction applied at right angles to the femur. They reported that this prevented rotation of the femoral condyles and counteracted the pull of the gastrocnemius muscle. The leg was then suspended in a Hodgen or a Thomas splint with a Pearson attachment. The great advantage of early muscle exercise was emphasized. In the patients treated by traction and early active exercise, union was much faster and more secure, and ultimate function of the knee was better than in those treated by any other method.

Non-union occurred only in patients who had open reduction and internal fixation; the authors considered this a strong argument for a non-surgical approach. They recommended that skeletal traction with two pins as described, with a definite, enthusiastic plan of muscle rehabilitation, be used for at least the first four to six weeks. After knee motion was established, plaster immobilization could be continued indefinitely without fear of residual stiffness in the knee and quadriceps femoris. The authors championed non-operative treatment of fractures of the distal third of the femur, including transverse, oblique, spiral, T and Y-condylar fractures of all types. They reserved operative treatment for all single condylar fractures with displacement.

The Care of the Infant with Subluxation of the Hip. Dr. Paul C. Colonna [16] reviewed the cases of thirty-eight patients less than eighteen months of age who had been treated for subluxation of the hip. He defined subluxation and differentiated it from dislocation and accepted the belief that dysplasia is caused by faulty growth development which may be due to familial, mechanical, hormonal, or genetic factors. The work of Caffey on examination of the hips in infants was discussed. The author questioned Caffey's feeling that infants thought to have stigmata of dysplastic hips were found to have normal hips.

Associated congenital anomalies in infants with subluxated hips were frequently found by the author, particularly metatarsus adductus, valgus calcaneus, and calcaneal deformities of the foot. In six of the cases a clear-cut family history of dysplasia was noted.

[14] Campbell Clinic, 869 Madison Avenue, Memphis 3, Tennessee.
[15] Campbell Clinic, 869 Madison Avenue, Memphis 3, Tennessee.
[16] Department of Orthopaedic Surgery, Hospital of the University of Pennsylvania, 3400 Spruce Street, Philadelphia, Pennsylvania.

Asymmetry of the thigh folds, limitation of abduction, shortening of limb length, and roentgenographic evidence of increased acetabular index were the common findings in subluxation and dislocation. If upward riding of the femoral head on roentgenographic examination or telescoping on physical examination were present, the case was more likely to be one of true dislocation. "Ortoloni's click" may be common in both conditions.

The author felt that the treatment of subluxation is best carried out by splints as early as possible and by the method of gradual abduction and external rotation. This method of treatment places the femoral head deep in the acetabulum, allowing normal development of the superior rim of the defective acetabulum. The length of time that splinting in abduction is necessary varied in his experience from a few to twenty-four months. A roentgenogram of the hip joint was used to determine when the splints could be discontinued. Of the thirty-eight patients treated for subluxation, all but two had excellent results.

Treatment of Fractures of the Calcaneus. Dr. Morton H. Leonard [17] realized that there is no panacea for the treatment of fractures of the calcaneus. Numerous methods have been proposed because of the deficiencies in end results and because of confusion regarding the pathological aspects. He felt that careful roentgenographic examinations were necessary before classification could be accomplished. He said that classifications simplified by regarding the state of the subtalar joint as the essence of a pathological condition and the status of this joint were deciding factors in whether conservative or surgical measures are indicated. He outlined closed management and believed that the open method after the method of Palmer is the treatment of choice for most fractures involving severe displacement of the subtalar joint. The mechanism of the fracture was described. He described and illustrated the technique.

On Friday, June 7, the meeting of the Section on Orthopaedic Surgery of the American Medical Association was combined with that of the Section on Physical Medicine of the American Medical Association and an excellent panel discussion on the question of the severely injured patient was presented. A period of discussion and questions from the floor followed the panel discussion and symposium. The moderators of this meeting were Dr. Edward L. Compere, representing the Section on Orthopaedic Surgery, and Dr. Lewis B. Newman, both of Chicago, Illinois, representing the Section on Physical Medicine. Formal presentations of the following papers were made.

The Immediate Care of the Injured Patient. Dr. Walter G. Maddock [18] said that the only swift care needed for the injured person in the emergency room is that required to stop vigorous bleeding, to combat shock, and to establish adequate respiratory function. Most bleeding in the extremities can be controlled by compression. Tourniquets have value but are often dangerous since they are commonly applied too loosely and obstruct the veins but fail to shut off the artery and thus increase the bleeding. The author noted that shock has been discussed for years. He said that if the patient has lost whole blood, he should have whole blood returned. Plasma is only a temporary substitute, and a point we seem to lose sight of is the use of Type O blood from the universal donor. It has been employed successfully for years with a very low incidence of reaction. Transfusion can be started intravenously during typing and cross matching.

As for respiratory function, Dr. Maddock said that one develops a great regard for the seriousness of hypoxia. Whether from a head injury or crushed thorax or any cause, proper pulmonary ventilation must be quickly established. It was pointed out that an old procedure now given its proper place in this regard is tracheotomy. It reduces the dead air space by approximately 100 cubic centimeters, and ease of respiration is facilitated by about 40 per cent, since three-fourths of the resistance is located above the tracheotomy. The author said that, for the injured patient with any question of airway difficulties, tracheotomy should be performed when first considered. The beneficial effects, including aspiration of the tracheobronchial tree, are clear, and the complications from infections, subcutaneous or mediastinal emphysema, hemorrhage or bronchial occlusion are rare. He stated that as soon as the existing serious complications demanding immediate attention are taken care of, a complete evaluation of the injuries without trauma or exposure is in order. Dr. Maddock emphasized the importance of an experienced staff man's being available for this phase of the care of the injured patient. Furthermore, multiple injuries are common now, and one must be able to evaluate injuries to the brain, spinal column, thorax, abdominal viscera, and extremities and to decide which requires first treatment and which can be logically handled later. He concluded that every hospital must have a plan for the care of the injured patient in order to reduce the mortality and morbidity from the thousands of accidents common to these times.

Neurosurgical Aspects. Dr. James C. White [19] said that in acute craniocerebral injuries three factors require primary consideration: (1) immediate evacuation of clots that compress the brain and produce pres-

[17] 520 Montana Street, El Paso, Texas.
[18] 250 East Superior Street, Chicago, Illinois.
[19] Massachusetts General Hospital, Fruit Street, Boston, Massachusetts.

sure coning at the tentorial notch or foramen magnum with lethal compression of the mid-brain or medulla oblongata; (2) débridement and closure of wounds to prevent infection; and (3) treatment of unconscious patients with diffuse contusion of the brain and cerebral oedema. In patients with spinal injuries the cord should be protected against further injury from vertebral fracture or dislocation. This is accomplished, Dr. White said, by recognition of paralysis at the site of the accident, proper transport to the hospital, and immediate immobilization of the fractured or dislocated vertebrae. Skull tongs and traction are best for treating cervical injuries and maintenance of normal lordosis in the lower portion of the spinal column. It was remarked that important early measures in high injuries are administration of oxygen, intravenous feeding until intestinal peristalsis recovers, and catheterization. In addition, tracheotomy and suction may be necessary to maintain an adequate airway; hourly turning in bed and skilled nursing care prevent decubitus ulcers. The author concluded that early operation is required only for the treatment of compound wounds and persistent cord compression, but should be deferred until respiratory exchange is adequate and peripheral circulation is competent.

Urological Aspects. Dr. James H. DeWeerd [20] pointed out that the possibility of significant trauma to structures of the urinary tract must be considered in all seriously injured persons, but particularly in patients who are injured in the trunk or pelvis. He said that the cardinal findings indicative of injury to the urinary tract are grossly bloody urine or discharge of blood from the urethral meatus. Furthermore, abnormal forces applied to the flank, upper abdominal or lower thoracic regions may result in injury to one or both kidneys. Pelvic injuries, particularly those which disrupt the bone arch or ring, are apt to have associated partial or complete disruption of the urethra and, less frequently, actual rupture of the vesical wall. It was pointed out that injury to the external genitalia and the pendulous portion of the urethra may be associated with trauma to the extremities or pelvis, and that trauma to the urinary tract in the first two areas demands immediate and careful diagnostic consideration. Accurate diagnosis and close observation may allow the more desirable conservative, that is non-operative, approach to problems of renal injury, except where specific indications demand immediate surgical intervention. However, the author said that intraperitoneal rupture of the bladder or disruption of urethral continuity demands immediate definitive operative care. Trauma to the external genitalia requires definitive care when the critical demands of the situation as a whole have been met.

Orthopaedic Aspects. Dr. H. Relton McCarroll [21] stated that the orthopaedic surgeon plays an important role in the management of the severely injured patient because of the high incidence of injuries to the musculoskeletal system. Treatment of a patient with multiple injuries demands a team approach and the orthopaedic surgeon must evaluate the musculoskeletal injuries in the light of the other problems. It was pointed out that obviously some injuries involving other systems will often take precedence over injuries to the musculoskeletal system and these must be investigated and treated before definitive treatment is attempted for the injuries of orthopaedic nature. He said that since, however, fractures and major injuries to soft tissues often involve the spinal column, pelvis, and extremities, the orthopaedic surgeon frequently represents the key man in the team concept of management. In the presence of injuries which are of greater immediate importance than the orthopaedic problem, he should request help from consultants in the fields involved.

He added that the presence of shock contra-indicates any immediate definitive treatment with reference to the musculoskeletal injuries other than simple immobilization for comfort and protection in order to decrease the incidence of progressive shock. Injuries to the brain, whether they be from intracranial contusion and hemorrhage or from a depressed skull fracture, should be investigated first by a neurosurgeon. It was pointed out that crushing injuries of the thorax which lead to varying degrees of embarrassment of respiration, the rupture of an abdominal viscus, the rupture of a kidney or the bladder, or the rupture of a major artery, such as occasionally occurs in fractures and crushing injuries of the extremities, take precedence over the immediate definitive treatment of musculoskeletal injuries.

These various problems were discussed in the light of their relationship to the orthopaedic problem. It was agreed that in those instances in which associated injuries are of mild degree and the major trauma consists of a compound fracture of one of the long bones of the extremities, immediate definitive treatment of the bone injury is required. A type of management which may be used in such a compound fracture and the principles of management involved in multiple injuries to the musculoskeletal system also were considered.

Plastic Surgery Aspects. Dr. Robin Anderson [22] reported that from the standpoint of the plastic surgeon, two rules should be followed:

1. Definitive plastic surgery should be deferred until the patient's condition has stabilized sufficiently to

[20] Section on Urology, Mayo Clinic, Rochester, Minnesota.
[21] Beaumont Medical Building, 3720 Washington Boulevard, St. Louis 8, Missouri.
[22] Cleveland Clinic, 2020 East 93rd Street, Cleveland 6, Ohio.

permit such surgical care without significant risk. With the help of antibiotics, even skin wounds can wait several days for primary closure.

2. The initial surgical treatment of a surface injury should be considered the final one whenever possible. He said that this implies that procedures such as the repair of lacerations be carried out with the same care and precise technique which would be expected of the plastic surgeon at a secondary operation.

Physiatric Aspects. Dr. Frederic J. Kottke [23] pointed out that restoration of the severely injured patient to his maximal functional ability requires that deterioration of the neuromuscular, circulatory, and connective-tissue systems be avoided during hospitalization. He said that within the limitations imposed by the requirements for treatment of shock, hemorrhage, lacerations, and fractures, measures should be instituted to maintain the flexibility of joints and suppleness of connective tissue and muscles. Trauma and bleeding in muscles and connective tissue accelerate fibrosis. Joint motion should be maintained whenever possible to prevent contracture from developing. He also said that prolonged immobilization or prolonged confinement in bed interferes especially with complete extension of the hip. Hip flexion contracture developed during long confinement in bed frequently prevents handicapped persons from standing and walking. Since flexion contractures of the hips are difficult to correct satisfactorily, adequate preventive care must be provided for bedfast patients. He concluded that muscular exercises should be begun to maintain contractility, nutrition, and strength of the muscles.

Chest Surgery Aspects. Dr. Lawrence M. Shefts [24] discussed the diagnosis and management of thoracic injuries in severely injured patients from the standpoint of progressive tension pneumothorax, hemopneumothorax, airway and chest-wall pain, and open wounds of the thorax. Emphasis was placed on resuscitation and methods of evaluation for surgical intervention.

[23] Department of Physical Medicine and Rehabilitation, University of Minnesota, The Medical School, Minneapolis 14, Minnesota.

[24] 510 Moore Building, San Antonio 5, Texas.

News Notes

The Virginia Orthopaedic Society held its Annual Business Meeting at the Shoreham Hotel in Washington, D. C., on October 29, 1957. The following officers were elected: Dr. J. Hamilton Allen, Charlottesville, *President;* Dr. George G. Hollins, Jr., Norfolk, *Vice-President;* and Dr. Richard H. Fisher, Roanoke, *Secretary-Treasurer*. The Annual Scientific Program will be presented at Charlottesville in April 1958.

Dr. Carl E. Badgley, Professor of Surgery in charge of the Division of Orthopaedic Surgery at the University of Michigan Medical School, was the first orthopaedic surgeon to act in the capacity of Orthopaedic Chief, *pro tempore*, at the Rhode Island Hospital. On November 7, 1957, he delivered the first Danforth Oration. This oration, to be given annually, honors the late Dr. Murray S. Danforth, Editor of *The Journal of Bone and Joint Surgery* at the time of his death in 1943. Dr. Badgley spoke on Traumatic Dislocation of the Hip.

Dr. Ralph K. Ghormley, head of the Section of Orthopaedic Surgery of the Mayo Clinic, Rochester, Minnesota, and Professor of Orthopaedic Surgery in the Mayo Foundation, Graduate School, University of Minnesota, was honored by his colleagues and former students at a dinner in Rochester on October 4, 1957. A traveling educational scholarship in orthopaedic surgery, named in honor of Dr. Ghormley and awarded to fellows in orthopaedic surgery at the Mayo Foundation, will be set up soon.

LILLY ENDOWMENT AWARD RENEWED

The American Orthopaedic Association through the Exchange Fellowship Committee, J. Neill Garber, *Chairman*, announces the continued support of the Exchange Fellowship project by Lilly Endowment, Inc. Two years ago Lilly awarded a grant to the Exchange Fellowship Fund in the amount of $5,000, one-half to be applied toward the American tour of British Visiting Fellows in 1956; the remainder to be used in 1957 for the combined American-Canadian group visit to Great Britain.

Lilly Endowment, Inc., has recently renewed its generous grant to the Exchange Fellowship Fund — again in the amount of $5,000, to be used over the next two years.

This announcement will be received with deep appreciation by American orthopaedic surgeons and with expressions of warmest thanks to Lilly Endowment, Inc., and, in particular, to Mr. and Mrs. J. K. Lilly of Indianapolis, for their interest and generosity in support of this auspicious and very worth-while Exchange program.

At the last meeting of the Board of Trustees of the **Orthopaedic Research and Education Foundation** nine applications for grants were approved for awards this year. The awards, totalling over $20,000.00, were as follows:

1. Investigator: Crawford J. Campbell, M.D. Work to be done at Albany Medical College, Albany, New York. Title of project: Injuries to Epiphyseal Plate in Dogs.

2. Investigator: Bruce M. Cameron, M.D. Work to be done at Baylor University School of Medicine, Houston, Texas. Title of project: Bone Grafts Placed on the Concavity of Fractured Bones.

3. Investigators: John Cobb, M.D., and Philip D. Wilson, Jr., M.D. Work to be done at the Hospital for Special Surgery, New York, N. Y. Title of project: Neurofibromatosis and Scoliosis.

4. Investigator: Jonathan Cohen, M.D. Work to be done at the Children's Medical Center, Boston, Massachusetts. Title of project: Three-Dimensional Anatomy of Haversian Systems in Bone (continuation of 1956 grant).

5. Investigator: W. F. Enneking, M.D. Work to be done at the University of Mississippi Medical Center, Jackson, Mississippi. Title of project: Histologic and Immunologic Investigation of Homogenous-Bone Transplants.

6. Investigator: Melvin J. Glimcher, M.D. Work to be done at the Massachusetts Institute of Technology, Cambridge, Massachusetts. Title of project: *In vitro* Studies of the Hydroxyapatite Crystal-Collagen Relationship.

7. Investigator: Henry O. Marsh, M.D. Work to be done at the Midwest Medical Research Foundation, Wichita, Kansas. Title of project: Stimulation of Leg Length by Use of a Distracting Force across the Epiphyseal Line.

8. Investigators: Thomas O. Shindler, M.D., and George G. Rose, M.D. Work to be done at Hermann Hospital, Houston, Texas. Title of project: A Study of Compression and Nutritive Factors on the Growth of Bone by Tissue Culture Methods (continuation of 1956 grant).

9. Investigator: Wayne O. Southwick, M.D. Work to be done at the Johns Hopkins University School of Medicine, Baltimore, Maryland. Title of project: Studies in Growth Mechanisms in Transplanted Bone.

The Board of Trustees of the Orthopaedic Research and Education Foundation wishes to thank the following orthopaedic societies for their pledges to the Foundation and to commend them for their support of the work that is being done:

The New Jersey Orthopaedic Society which pledged $1,000.00;
The Louisiana Orthopaedic Association which pledged $250.00;
The Ohio Orthopaedic Society which pledged $100.00;
The Texas Orthopaedic Association which pledged $200.00;
The Orthopaedic Research Society which pledged $200.00.

The next deadline for applications for grants by the **Orthopaedic Research and Education Foundation** is June 1, 1958. Applications received after that date will be deferred until January 1959. Application blanks may be obtained from: Harold A. Sofield, M.D., *Secretary-Treasurer*, Orthopaedic Research and Education Foundation, 116 South Michigan Avenue, Chicago 3, Illinois.

The Fall Meeting of the **New Jersey Orthopaedic Society** was held on Saturday, October 10, 1957, at St. Joseph's Hospital in Paterson. A symposium of fractures was presented; Dr. David M. Bosworth acted as Moderator. The following papers were read:

Vertical Fractures of the Patella: Dr. Sidney Brooks;
Fractures of the Tibial Shaft Treated with the Lottes Nail: Dr. Robert V. Holman;
Fractures of the Femoral Shaft: Dr. A. J. Santoro;
Fractures of the Os Calcis Treated by the Palmer Operation: Dr. Andrew C. Ruoff III;
Supracondylar Fractures of the Humerus Treated by Traction: Dr. Jack C. Warburton;
The Mechanism of Fatigue Fractures: Dr. Harold M. Frost;
Estimation of Fracture as to Result Obtained: Dr. David M. Bosworth;
Dupuytren's Contracture: Dr. Emanuel B. Kaplan;
Presentation of Bone Tumors: Dr. R. R. Goldenberg.

The **Orthopaedic Guild** held its Eighteenth Annual Meeting in Louisville, Kentucky, November 8 and 9, 1957, in cooperation with the Department of Surgery of the University of Louisville School of Medicine. The program was as follows:

Refrigeration and Hibernation Treatment in Head Trauma: Dr. R. Glenwood Spurling, Dr. Everett G. Grantham, and Dr. Ludwig H. Segerberg;
Vascular Conditions Simulating Orthopaedic Diseases: Dr. Alvin B. Ortner and Dr. Berg;
Metallic Fixation in Metastatic Fractures of the Femur: Dr. Harry Goldberg and Dr. Ellis;
Treatment of Fractures of the Neck of the Femur with a Smith-Petersen Nail and Wood Screw: Dr. Richard Hudson;
Treatment of Scapulothoracic Syndrome: Dr. Morgan Colbert;
Excision of the Greater Multangular Bone for Mobilization of the Thumb: Dr. Leonard Goldner;
The Use of Lottes Intramedullary Nails in Non-union of the Tibia: Dr. Allen Zoeller;
The Correction of Spinal Deformities in Chronic Arthritis: Dr. John G. Kuhn and Dr. Theodore A. Potter;
The Present Status of Interbody Spine Fusion: Dr. William Massie;
Presentation and Review of Over 100 Cases of Interbody Fusion by the Anterior and Extraperitoneal Route: Dr. Paul Harmon;
Presentation of a Group of Giant-Cell Tumors: Dr. Kenton Leatherman;
Tubercular Knees in Children: Dr. James Riley, Dr. Daniel Costigan, and Dr. Coy;
Eosinophilic Granuloma. Presentation of Cases: Dr. Armand Fischer;
Bickel-Moe Procedure (Translocation of the Peroneal Tendon for a Weak Heel Cord): Dr. William McDaniel Ewing and Dr. Nader;
Skeletal Maturity as Related to Orthopaedic Surgery: Dr. Frank Falkner;
Congenital Scoliosis. Presentation of Cases: Dr. Kenton Leatherman.

Book Reviews

OUTLINE OF ORTHOPAEDICS. John Crawford Adams, M.D., F.R.C.S. Baltimore, The Williams and Wilkins Co., 1956. $7.00.

In his preface Mr. Adams says the outline "is intended primarily to help students who are studying for the qualifying examinations" and he hopes "it may also be of use to practitioners whose work brings them into occasional contact with orthopaedic problems, and to physiotherapists and orthopaedic nurses." I might agree with the second thought expressed but feel that he has done himself little justice with the first. This is a handsomely done, succinct, and readable account of a large field of medical practice. It covers a vast amount of material; yet is so well organized and logically presented that the result is an integrated whole.

The first chapter entitled "Clinical Methods" outlines the method of "approach to orthopaedic problems," the history, clinical examination, roentgenographic examination, and laboratory studies. The portion dealing with the clinical examination and its importance is excellent and nothing could be more sound than his introductory remark that the "inexperienced surgeon who tackles the problem methodically step by step will often give better account of himself than his more experienced colleague who makes a 'snap' diagnosis after but a cursory examination." Another bit of sound philosophy is expressed further in the chapter entitled "'Functional' or 'Psychogenic' Disorders." "When the cause of a patient's symptoms remains obscure, despite a thorough investigation, there is a prevalent tendency, it has almost become fashionable, to discount the genuineness of the symptoms and to ascribe them to 'hysterical', 'functional', or 'psychogenic' factors. This must be deplored as a dangerous policy that has led on countless occasions to a serious organic disease being overlooked. Just because we fail to discover the cause of a particular symptom, it by no means follows that the symptom is imaginary. It usually means only that we are not sufficiently skilled in diagnosis." I am sure this counsel is applicable to more than "students studying for the qualifying examinations." There follows in this same section a general discussion of the treatment of orthopaedic disorders.

The second chapter is a general survey of orthopaedic disorders, their diagnosis, and the current concepts of management without specific reference to their regional manifestations.

The remainder of the book is devoted to the regional consideration of the topics discussed in Chapter Two. One chapter is devoted to each region, for example, the neck and cervical spine, the trunk and spine, and the shoulder region. At the beginning of each of these chapters are one or more paragraphs of general discussion of the region to be described followed by a listing of the specific entities covered. There also are several pages devoted to a discussion of the special points in the investigation of each region with a helpful outline of the pertinent features of the associated clinical examination.

Certain criticisms of the book seem justified. There is little mention of fractures. (This subject is presented in a companion volume.) Since the possibility of fracture is often one of the points in diagnosis to be considered in any patient some inclusion of principles of examination for such would not seem unwarranted or amiss in the first chapter dealing with the approach to orthopaedic problems. Second, more discussion of muscle spasm and spasticity and the importance of each as physical signs would seem in order—spasm alone, is mentioned and that parenthetically.

In the general section dealing with osteomyelitis and septic joints as well as in the sections dealing with these conditions as they are locally manifested the statement is repeatedly made to the effect that "Radiographs show no alteration from normal in the early stages." I believe that this is quite untrue and that a good opportunity for teaching has been missed. If one concerns himself solely with bone and its responses to infection the statement certainly is true, but there is more than that to be seen on the initial roentgenogram; and an investigation of the soft tissues, their contours, the presence or absence of the normal planes between them, and the vascular pattern of the affected area is exceedingly important and helpful and may reveal valuable information.

Some topics not included in this edition might be included in subsequent ones, namely: eosinophilic granuloma, spastic flat-foot, tarsal coalitions, and the relationship of tight heel cords to foot symptoms. In the section on examination of the foot the importance of inverting the hind part of the foot to lock the calcaneus beneath the talus before testing dorsiflexion could be mentioned.

There is no bibliography. There is some inconsistency in attaching names to procedures, for example, in discussing treatment of osteo-arthritis of the hip the following appears (1) cup arthroplasty, (2) replacement arthroplasty, (3) excision arthroplasty (Girdlestone pseudarthrosis). Perhaps this is the author's way of defining the specific excision arthroplasty he prefers. If so, his illustration of replacement arthroplasty is equally specific. I believe in such instances it would be better to burden the students with the names of the surgeons who pioneered in these procedures or none at all.

In summary, this is an excellent book. It is a masterpiece of organization, and it is a pleasure to read. In addition to those for whom it is written, it will appeal as an aid to any who find it necessary to organize lectures for students, nurses, and therapists from time to time.

J. Drennan Lowell, M.D.

DEGENERATIVE CHANGES IN THE STERNOCLAVICULAR AND ACROMIOCLAVICULAR JOINTS IN VARIOUS DECADES. Anthony F. DePalma, M.D. Springfield, Illinois, Charles C. Thomas, 1957. $5.50

After completing a study of the anatomy and various aging changes in the glenohumeral joint, DePalma turned his attention to the two other joints of the shoulder girdle. The method of the previous study and the present study is the same as that in the famous survey of the human knee joint in various decades of life by Bennett, Waine, and Bauer in 1942. DePalma found that some acromioclavicular joints showed degenerative changes as early as the second, and some sternoclavicular joints as early as the third decade. The clavicular surface of the sternoclavicular joint deteriorated more rapidly than the sternal surface. No such difference was noted in the articular surfaces of the acromioclavicular joint. The right joint showed a greater degree of degenerative change than the left. The synovial membrane, in contrast to the articular cartilage, showed relatively little that was of any pathological significance. The later stages of the degenerative change was generally apparent in roentgenograms of the subchondral bone. The author resisted the temptation to correlate the necropsy observations with generally known findings in conditions commonly termed degenerative joint disease. One wonders about the condition of some of the weight-bearing joints in the same subjects. There is much to be learned about aging of articular cartilage from histochemical techniques, electron microscopy, and other new tools of our time. Analyses for hydroxyprolene for collagen and hexosamines for ground substance of cartilage may supply pertinent information that should be forthcoming in decade studies on joints in the future. This book can be recommended to those who do investigative work on the shoulder girdle.

Marshall R. Urist, M.D.

WILLIAM HARVEY. HIS LIFE AND TIMES: HIS DISCOVERIES: HIS METHODS. Louis Chauvois. New York, Philosophical Library, 1957. $7.50.

This book is the offspring of an unhappy marriage of the scientific method to literary pretentiousness. All respect is due to the author for his research and his undoubted authority on the life and work of Harvey. The mass of material he has collected is enormous. He has used it all to the last footnote to a footnote.

The style is that of the lecturer who rarely steps aside to permit an unobstructed view of his subject. The lecturer's estimate of his audience is too evident. They know some medicine, a little medical history, and nothing about anything else. Even more open to criticism are the long sequences in which the author reconstructs Harvey's thoughts. This, the scholarly biographer maintains, is a trick of the popularizer. You can report what a man did, what he said, what he wrote, and draw your own conclusions. When you attempt to report what he thought you have crossed the border into fiction.

The author's effort to rewrite in terms of Harvey one of the most crowded periods of English and European history is unnecessary, superficial, and belittling. The greatness of William Harvey is not made greater by imagining contacts of which there is no record with the famous and infamous men of his time.

This book is a vast compendium of facts and curiosa both medical and historical. It would be an invaluable sourcebook for a biography of William Harvey.

J. A. R.

BONE TUMORS. GENERAL ASPECTS AND AN ANALYSIS OF 2,276 CASES. David C. Dahlin, M.D., Springfield, Illinois, Charles C. Thomas, 1957. $11.50.

For the next two decades, at least, no study of bone tumors can ignore this new monograph. In it Dahlin has analyzed the pertinent material from the Mayo Clinic, the largest series of cases from any one source reported to date. Over 2,000 tumors are classified. Each main category of bone tumor is accorded a chapter, in which is described in some detail the observed clinical, roentgenographic, and pathological characteristics.

The work, most of which has previously appeared in recent journals as separate reports on each entity, adds the analyses of the unreported tumors to achieve complete coverage. Such a body of material, collected in conformity with the high professional standards of the Mayo Clinic, affords an unparalleled opportunity compared with registry collections of similar size.

For the first time, we have a good break-down of the prevalence of each type of tumor in the general group, based upon uniform standards of diagnosis. It may be argued that the case material of the Mayo Clinic, including the large proportion of referrals, does not accurately reflect incidence of specific entities in the population as a whole, but at least it gives us an order of magnitude. Other studies of incidence, such as large hospital populations or registries, are open to the objection of even more inadequate sampling, based on small numbers of cases, or selection of cases, or population bases restricted by age or sex. Since the present collection represents all cases seen before 1956, it is to be hoped that a more detailed correlation of incidence of these tumors to the population of the Clinic from year to year will appear in subsequent editions.

Dahlin uses a classification similar to that of Lichtenstein. Where there are significant disputes concerning classification, and in other matters as well, he takes a conservative stand, on the whole, and usually indicates the grounds for exception.

The outstanding merit of this book is the handling of the histopathology. The photomicrographs are superbly selected and well reproduced. This is the best guide presently available for the beginner's evaluation of the microscopic character of the bone tumors. Of course, limitations of space prevent representations of the infinite variety of patterns encountered in practice, and only actual study of many slides can provide the

measures of variation. The text indicates the difficulties to be encountered in atypical cases, but elects to present a simplified and perhaps dogmatic view of typical cases rather than obscure the essentials by detail. In this way, the book can serve as a fundamental text for orthopaedists or a working manual for pathologists who encounter only the occasional bone tumor.

This approach minimizes the amount of text needed, and a rather large number of illustrations combined with a lavish use of space make for easy readibility and ready reference.

The principal fault of the work as a standard reference is the omission of details. For example, one would like to know how many osteochondromata are of the multiple type and how many are single, in view of the tenfold difference in incidence of malignancy in the two groups. The inclusion of the chondromata of the hands and feet, which hardly ever become malignant, with those of the larger bones of the extremities and girdles, which often become malignant, deprives us of adequate assay of the tendency to malignancy of this tumor. Similar omissions in details of the treatment, course, and outcome of groups of cases may hamper those seeking specific information. In general, however, Dahlin fully accomplishes his stated purpose—a general review of the Mayo Clinic material with emphasis on histopathological diagnosis.

One may object to his inclusion of all lymphomata under reticulum-cell sarcoma, to his omission of any of the newer treatment methods under investigation, or to the absence of theoretical considerations including the role of radiation in the production of bone tumors, but one can only congratulate the author on a valuable contribution, answering many of the needs of students, practitioners, and specialists. This book should be in the library of every orthopaedist and should be required reading for those in training.

Jonathan Cohen

ARTIFICIAL LIMBS IN THE REHABILITATION OF THE DISABLED. R. Langdale Kelham, M.D., O.B.E., F.R.C.S. London, Her Majesty's Stationery Office, 1957.

As a compendium, digest, or guide to the surgeon's role in the prescription, fitting, and training in use of artificial limbs, this is a good treatise. The English limb surgeon apparently assumes the functions of our prosthetic team. There is no mention of consultation among surgeon, trainer, limbfitter, and others concerned in the care of the patient, which practice has been found so fruitful in our prosthetic centers.

The volume is well organized. It covers the various aspects of the surgeon's relation to prosthetic problems in a logical and concise manner. It stresses the importance of the postoperative, pre-fitting program of therapy. There is a generous discussion of the components and types of prostheses, with a special section devoted to the peculiar problems of women and children. The use of pylons, which is almost universal in unilateral above-the-knee amputees, and temporary legs, is stressed. Special mention is made of the manner of fitting unconventional types of stumps. The psychological trauma attending amputation, which is often neglected, and the frequent necessity for psychotherapy is discussed.

There is a fine section on training in which the organization, staff, equipment, and methods used are outlined. The commonly met stump complications are adequately covered. There is some speculation on the origins of phantom pain.

The illustrations are excellent. The book would be improved if there were more of them and if they were inserted opposite their appropriate place in the text, instead of being massed together at the end of the volume.

The prosthetic experience and practice of the Roehampton group parallels that in this country in many areas. Their insistence on pre-fitting stump conditioning, the prescription of the device best suited to the individual, and the necessity for adequate training in prosthetic use are in accord with the best practice on this side of the Atlantic. Their "passing-out" like our "check-out" ensures good fit and workmanship. The use of elephant boots or rocker-bottom pylons for bilateral above-the-knee amputees and the preservation of epiphyses when children's extremities are amputated are advocated by them and by us. The Canadians have persuaded them and us that the Syme amputation provides an excellent stump.

In some areas we are not in accord with the English prosthetic practice. They still adhere to the so-called sites of election in the upper extremity, which we believe to be obsolete. They favor a relatively short below-the-knee stump. They are more enthusiastic about knee disarticulation than we are.

The Roehampton armamentarium appears to be deficient in several respects. Their upper extremity and Syme prostheses are still fabricated from heavy sweat-collecting leather and steel, instead of the lighter and more sanitary laminated plastic used on this continent. They still use the stretchable and inefficient leather thong to activate the forearm and terminal devices in many artificial arms. They describe several types of hand, only to condemn them. There is no mention of the A.P.R.L. hand or any hand with flesh-colored plastic covering. They prescribe the heavy, cumbersome tilting table prosthesis, which is hard to keep in good repair, for patients with hip disarticulation. The lighter, cleaner, more efficient Canadian hip disarticulation prosthesis is not included.

In accordance with long-established practice, they use all sorts of detachable gadgets for holding toilet articles, tools, and cutlery which we think superfluous and burdensome to the patient. The English preference for metal rather than wooden legs is well known. One senses that they lack craftsmen who can accurately fit wooden sockets. This could account for their unhappy experiences with the suction socket. They stick to the old triangular-shaped socket, which is slightly higher anterolaterally than ours and which is

rolled over at the top. In the section on complications considerable space is given the "roll of flesh" or adductor roll. Extension of the anterior wall of socket so that the roll can be pulled into it is mentioned but not stressed. The rectangular-shaped socket with high anterior and lateral walls developed by the University of California, Berkeley, which is becoming increasingly popular here, is not mentioned.

Extensive studies in locomotion of normal people and amputees during the past twelve years have shown that function of artificial legs is dependent to a considerable extent on proper alignment. A well fitting device, if misaligned, may be unacceptable to the amputee by reason of pain, poor function, or its demand for an excessive energy output. A discussion of locomotion and its relation to alignment is not included in this volume. Shoulder suspension for above-the-knee prostheses, long regarded as outmoded here, is apparently often used in Great Britain.

On this continent, harnessing is usually regarded as of critical significance in comfort and function, particularly for upper-extremity prostheses. In our prosthetic schools and manuals it is given considerable promience because of its extreme importance. The volume herein discussed accords the subject passing mention in delineating the various standard types of artificial arms, but does not relate harnessing *per se* to the functioning of the prosthesis.

Three other glaring omissions are evident in this book; the paucity of references, the absence of consideration of cineplastic arms, and lack of any mention of contra-indications to fitting.

The volume ends on an encouraging note as to employability and earning capacity of amputees.

This reviewer feels that the volume is probably an excellent summation of the experience and practice of the Roehampton group over a period of years. Beneath the surface, however, is an indication of lack of familiarity with progress in prosthetics in areas outside Great Britain during the past decade.

Robert Mazet, Jr.

THE AMERICAN ORTHOPAEDIC ASSOCIATION

At the Annual Meeting of The American Orthopaedic Association held at the Homestead in Hot Springs Virginia, the following were elected to membership:

Honorary Membership

John P. Caffey, New York, N. Y.

Corresponding Membership

Carlos E. Ottolenghi, Buenos Aires, Argentina
G. T. du Toit, Johannesburg, South Africa

Active Membership

George T. Aitken, Grand Rapids, Michigan
Alvin J. Ingram, Memphis, Tennessee
William A. Larmon, Chicago, Illinois
Robert Mazet, Jr., Los Angeles, California
Newton C. Mead, Evanston, Illinois
John J. Niebauer, San Francisco, California
Edgar L. Ralston, Philadelphia, Pennsylvania
Daniel C. Riordan, New Orleans, Louisiana
Marcus J. Stewart, Memphis, Tennessee

The Membership Committee is as follows: Walter C. Graham, Santa Barbara, California, *Chairman*, Frank E. Stinchfield, Robert A. Knight, Albert C. Schmidt, and Julian E. Jacobs.

Carter R. Rowe, Boston, Massachusetts, is Chairman of the Program Committee; associated with him are Robert W. Johnson, Jr., and James A. Speed.

The next Annual Meeting of The American Orthopaedic Association will be held jointly with The British Orthopaedic Association at The Shoreham, Washington, D. C., May 11 to 16, 1958.

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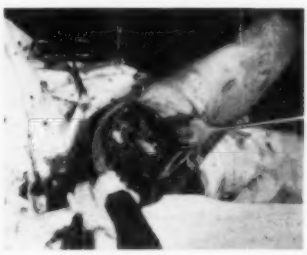

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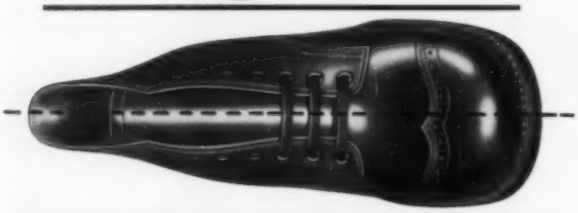

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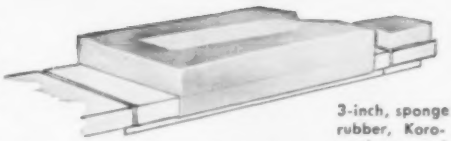

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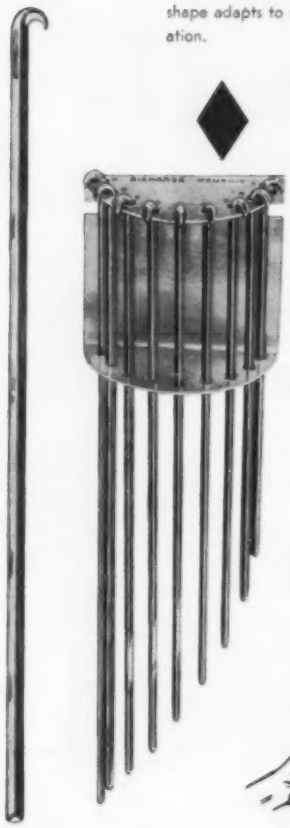

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By Alfred Rives Shands, Jr., B.A., M.D., Medical Director of the Alfred I. duPont Institute of the Nemours Foundation; in collaboration with Richard Beverly Raney, B.A., M.D. 1957, 5th edition, 725 pages, 5⅜" x 8½", 214 illustrations. Price, $9.75.

More popular than ever, the fifth edition of Shands' Handbook of Orthopaedic Surgery gives an up-to-date presentation of the fundamentals of diagnosis and treatment of orthopaedic cases. Written in a clear, terse and understandable manner with an up-to-date bibliography, this is a handbook that can be of constant help to you in solving problems involving orthopaedic surgery and particularly in diagnosis. Instructively helpful photographic illustrations have replaced most of the line drawings used in earlier editions. Seventeen short, new discussions have been added and chapters on General Affections of the Skeleton have been rearranged for clearer presentation and to keep this revision abreast of current thinking and recent advances in the field.

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Editor: J. S. Speed, M.D., Associate Editor: Robert A. Knight, M.D., Memphis, Tenn. With 17 Contributors. 1956, 2124 pages, 6½" x 10", 1323 illustrations, two volumes (68-page Index in Each Volume). Price, $40.00.

In this greatly expanded revision, the editors and contributors have placed greater emphasis on the fundamentals of operative orthopaedics, particularly in regard to indications and contraindications for operations and in the choice of the proper operative procedure where more than one method is available.

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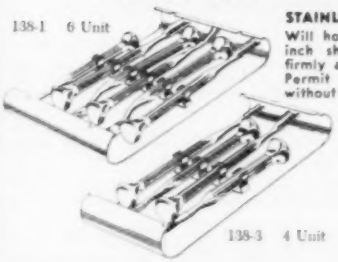

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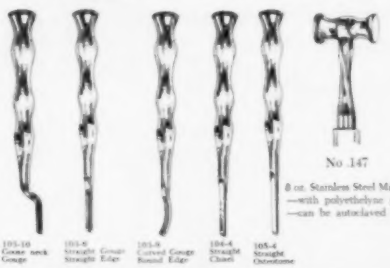

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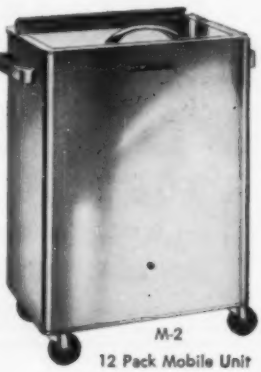

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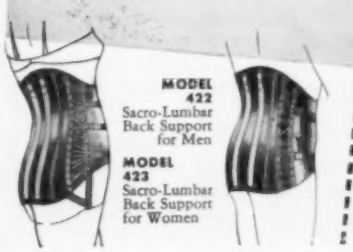

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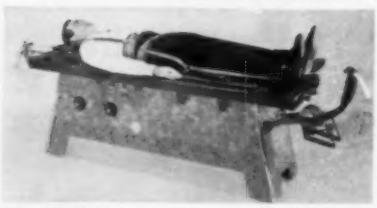

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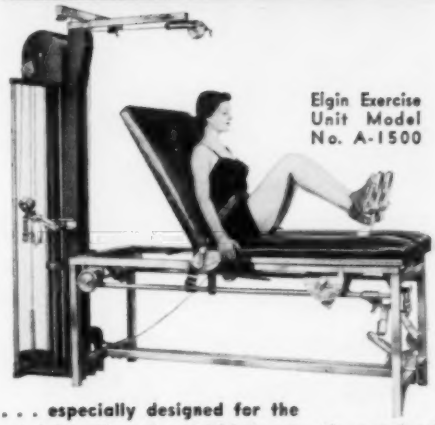

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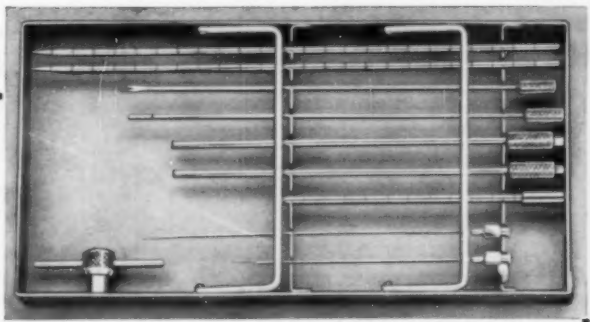

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REFERENCE: The Journal of Bone & Joint Surgery, Volume 33-A, No. 1; page 93 et al., January, 1956. As described in Armamentarium, Vol. II, No. VI.

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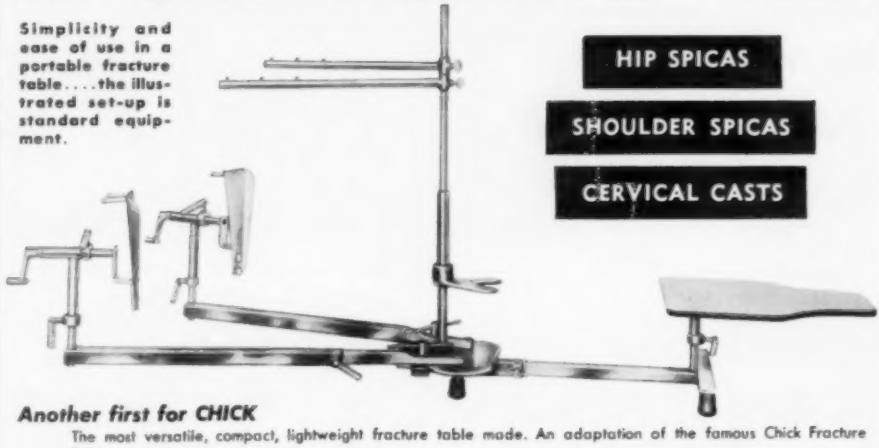

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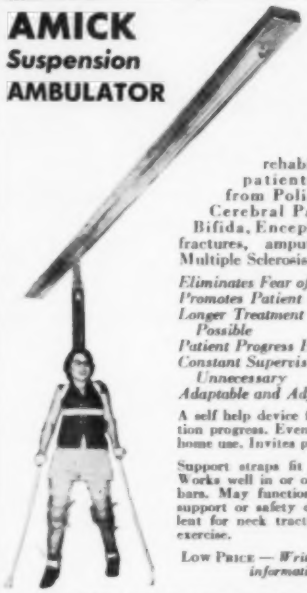

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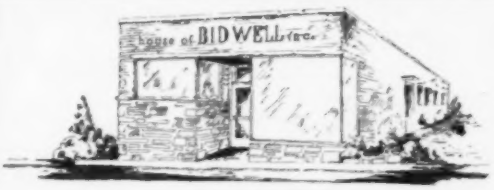

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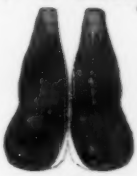

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ADDRESSES OF CONTRIBUTORS
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WAYNE H. AKESON, M.D., Department of Surgery, Division of Orthopaedic Surgery, University of Chicago, Chicago 37, Illinois

RICHARD ALLEN, M.D., 191 College Street, Battle Creek, Michigan

R. J. D. ANDERSON, M.B., B.S., African Inland Mission, Kapsabet, Kenya

CARL E. BADGLEY, M.D., 1313 East Ann Street, Ann Arbor, Michigan

GÖRAN C. H. BAUER, M.D., Malmö Allmänna Sjukhus, Malmö, Sweden

DAVID M. BOSWORTH, M.D., 742 Park Avenue, New York 21, N. Y.

JOSEPH H. BOYES, M.D., 1401 South Hope Street, Los Angeles 15, California

D. A. CAMERON, M.D.S., Pathology Department, University of Sydney, Sydney, Australia

BRADFORD CANNON, M.D., 330 Dartmouth Street, Boston 16, Massachusetts

M. R. CHAUDHRI, M.B., B.S., District Hospital, Meru, Kenya

MATHER CLEVELAND, M.D., 115 East 61st Street, New York 21, N. Y.

DAVID C. DAHLIN, M.D., Mayo Clinic, Rochester, Minnesota

PAUL H. DEVRIES, M.D., The Tucson Clinic, 116 North Tucson Boulevard, Tucson, Arizona

LILLIAN EICHELBERGER, Ph.D., Department of Surgery, Division of Orthopaedic Surgery, University of Chicago, Chicago 37, Illinois

J. WILLIAM FIELDING, M.D., 136 Depew Street, Dumont, New Jersey

JOSEPH L. FLEMING, M.D., 7360 LaSalle Boulevard, Detroit 6, Michigan

NICHOLAS J. GIANNESTRAS, M.D., Suite 1001, Carew Tower, Cincinnati 2, Ohio

W. SCOTT GILMER, M.D., 869 Madison Avenue, Memphis 3, Tennessee

CHRISTOPHER GLENNEY, M.D., 25 Main Street, Norwich, Connecticut

WALTER C. GRAHAM, M.D., 1421 State Street, Santa Barbara, California

S. L. HAAS, M.D., 450 Sutter Street, San Francisco 8, California

J. TED HARTMAN, M.D., 62-A New Road, Headington, Oxford, England

GEORGE JACOBSON, M.D., 1200 North State Street, Los Angeles 33, California

JOSEPH M. JANES, M.D., Mayo Clinic, Rochester, Minnesota

PATRICK J. KELLY, M.D., Mayo Clinic, Rochester, Minnesota

W. H. KIRKALDY-WILLIS, M.D., F.R.C.S., Orthopaedic Centre, P. O. Box 30195, Nairobi, Kenya

ROBERT A. KNIGHT, M.D., 869 Madison Avenue, Memphis 3, Tennessee

PROF. DR. GERHARD B. G. KÜNTSCHER, Hafenkrankenhaus, Hamburg 11, Germany

G. KENNETH LEWIS, M.D., 6 North Michigan Avenue, Chicago, Illinois

G. DEAN MACEWEN, M.D., 869 Madison Avenue, Memphis 3, Tennessee

MICHAEL L. MASON, M.D., 154 East Erie Street, Chicago 11, Illinois

VICTOR G. MIKITY, M.D., 1200 North State Street, Los Angeles 33, California

WILLIAM L. MINEAR, M.D., 17 Encino Medical Plaza, Albuquerque, New Mexico

C. LESLIE MITCHELL, M.D., Henry Ford Hospital, Detroit 2, Michigan

THOMAS H. NEWTON, M.D., Peter Bent Brigham Hospital, 721 Huntington Avenue, Boston, Massachusetts

ROBERT D. RAY, M.D., University of Illinois College of Medicine, 840 South Wood Street, Chicago 12, Illinois

ROBERT A. ROBINSON, M.D., The Johns Hopkins Hospital, Baltimore 5, Maryland

MR. MICHAEL ROMA, Department of Surgery, Division of Orthopaedic Surgery, University of Chicago, Chicago 37, Illinois

GLENN A. SANFORD, M.D., 1775 East 14 Mile Road, Birmingham, Michigan

HUGH SMITH, M.D., 869 Madison Avenue, Memphis 3, Tennessee

PANAYIOTIS SMYRNIS, M.D., c/o J. Batillas, M.D., 23-95 32nd Avenue, Long Island City 5, New York

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